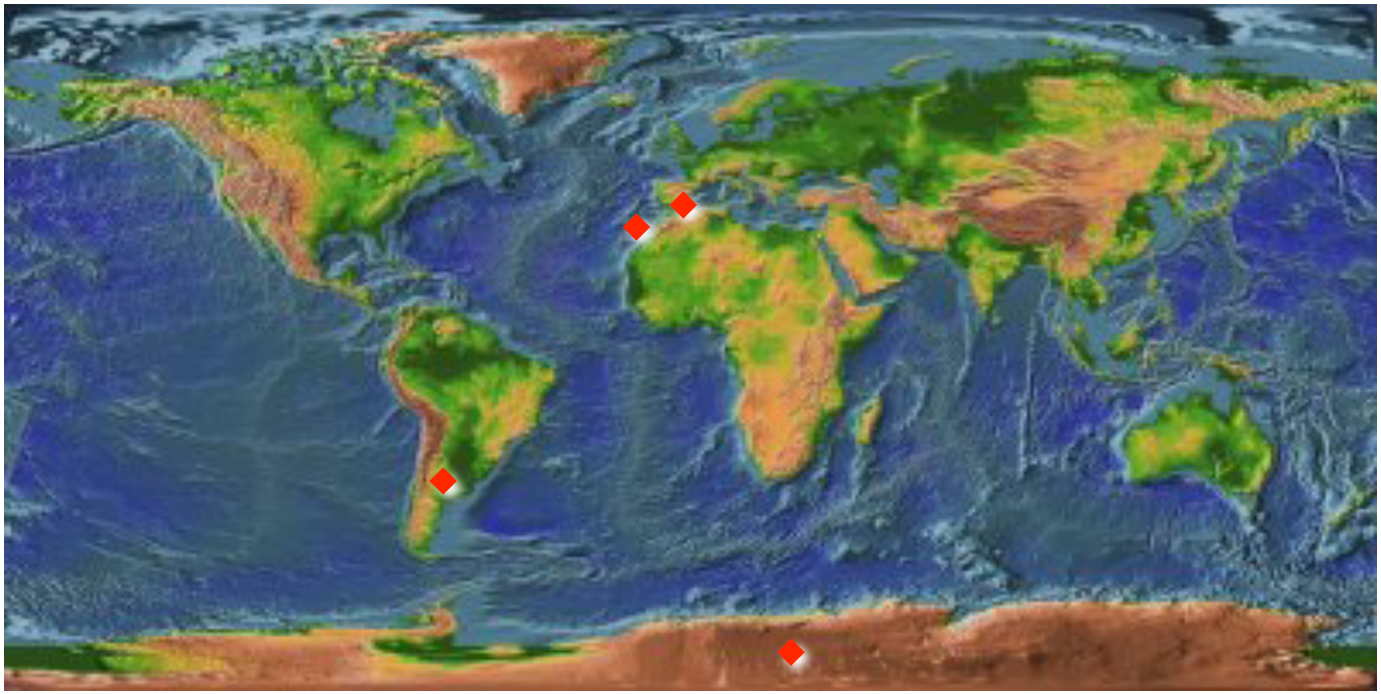
CMB experiments at European sites

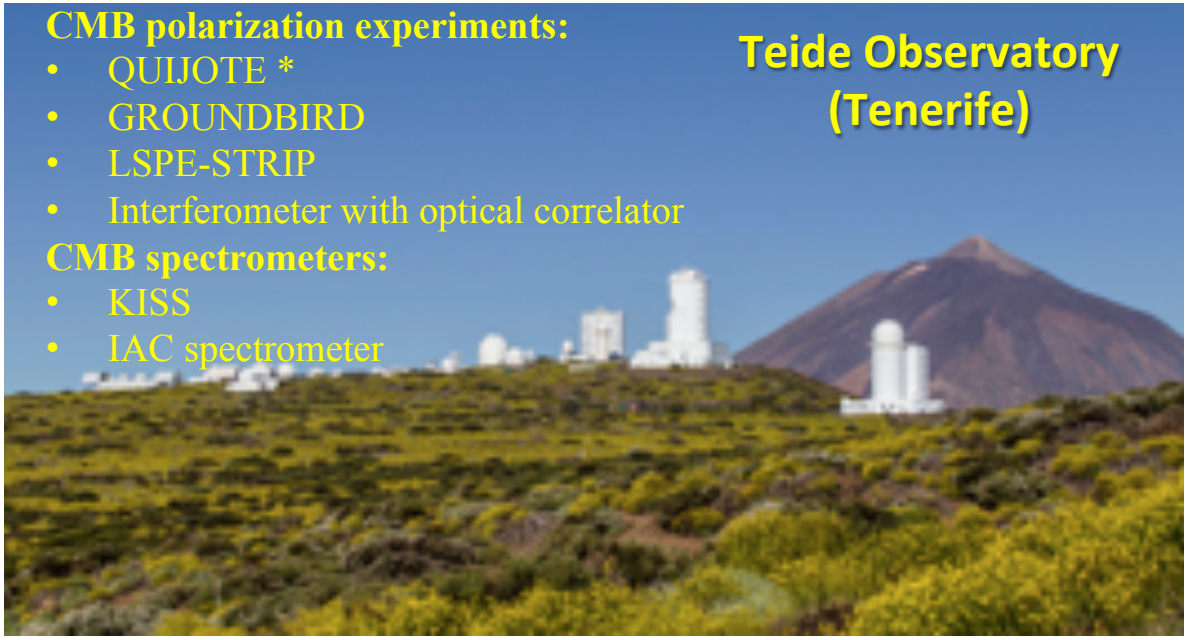


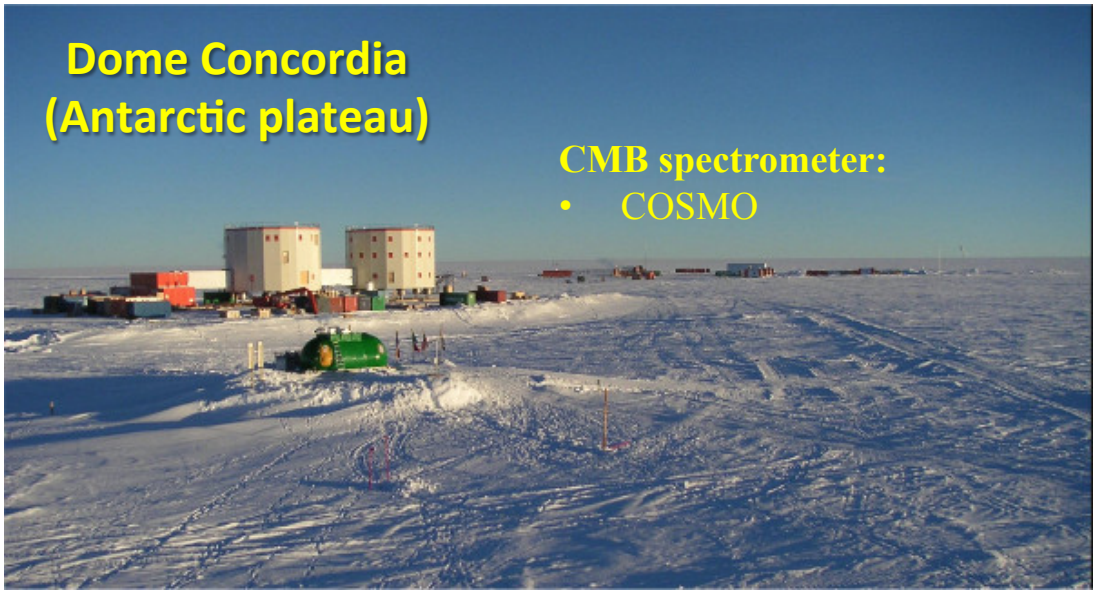
(Tenerife, Pico Veleta, DOME-C, LLAMA)

J.A. Rubiño-Martín (IAC)
With contributions from: E. Battistelli, M. Bersanelli, K. Ganga, R. Génova-Santos, S. Henrot-Versillé, R. Hoyland, J. Macías-Pérez, S. Masi.

Florence, September 6-7, 2017

CMB experiments at European sites





(* = in operation)

Teide Observatory (Tenerife)

- Altitude: 2.400 m
- Longitude: 16º 30' W
- Latitude: 28º 17' N
- Typical PWV: 3 mm, and below 2mm during 20% of time.
- High stability of the atmosphere.
- Good weather: 90%
- Long history of CMB experiments since mid 80s.

Tenerife experiment
10, 15, 33 GHz

COSMOSOMAS
11, 13, 15, 17 GHz

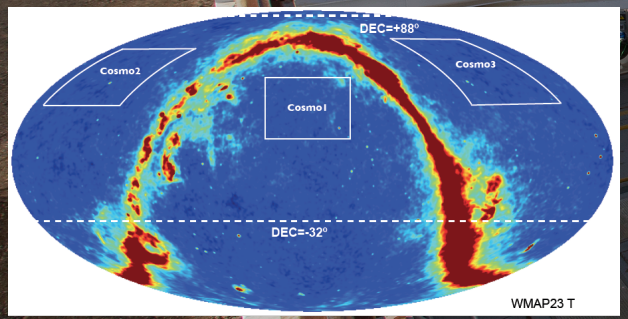
The Very Small Array
30GHz

The QUIJOTE experiment

Q-U-I Joint Tenerife CMB experiment

QT1.
Instrument: MFI.
11, 13, 17, 19 GHz.
FWHM=0.92º-0.6º
In operations since 2012.

QT2.
Instruments: TGI and FGI
30 and 40 GHz.
FWHM=0.37º-0.26º
In operations since 2016.



INSTITUTO DE ASTROFISICA DE CANARIAS · IAC

IFCA Instituto de Física de Cantabria

DICOM

UNIVERSITY OF CAMBRIDGE

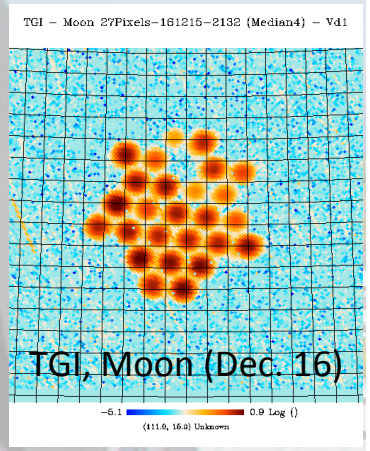
MANCHESTER 1824 The University of Manchester

idom

QUIJOTE project: current status

MFI (10-20 GHz). In operations since Nov 2012.

- 4 horns, 32 chan, 4 bands: 11, 13, 17, 19 GHz, 400-600 μK $s^{1/2}$ per channel.
- Observations (> 21,000 hrs completed): COSMO fields (> 5,200 h), Wide survey (>8,500 h), galactic fields (Taurus, W49, IC443, W63, FAN, galactic center). Results published in Perseus and W43 (Genova-Santos et al. 2015; 2017). Best upper limit to date on AME pol fraction (0.2%).
- **MFI upgrade**. Funds secured. Aim: to increase the speed by at least a factor of 3. Two-years for development.
- A replica of a single pixel to be installed in ZA (HartRAO 7.6m antenna).
- **RADIOFOREGROUNDS** project (public results during 2018).



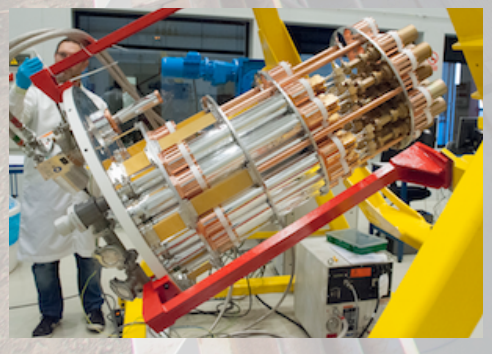
TGI, Moon (Dec. 16)

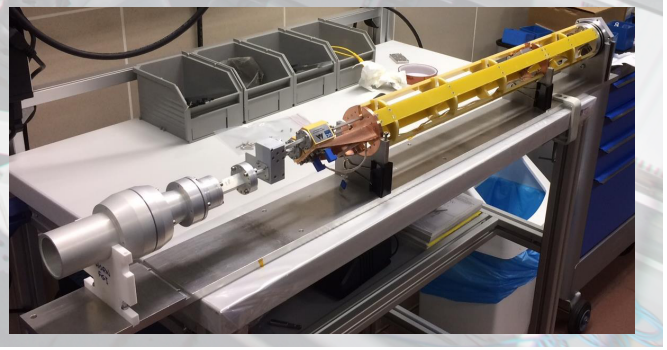
TGI (30 GHz).

- All 30 receivers integrated during 2016.
- Commissioning of 27 pixels started early 2017.

FGI (40 GHz).

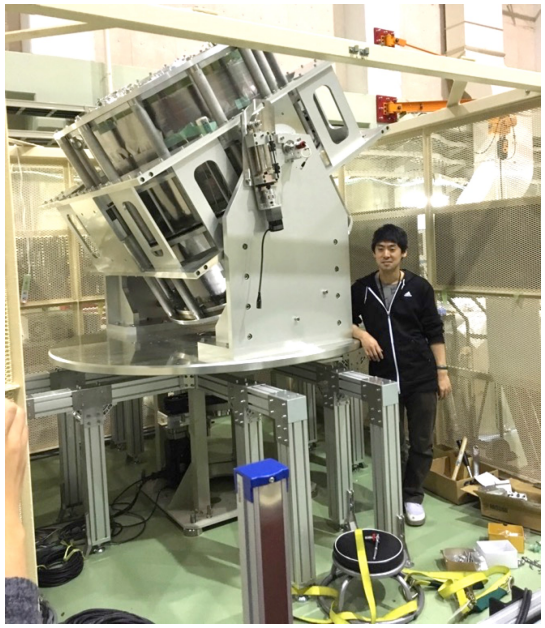
- First 10 receivers integrated in June 2017. All components for 30 pix available.
- Now in the process of integrating receivers in the cryostat. Joint TGI/FGI operation.
- Observing plan for TGI/FGI science phase: cosmo survey in 3 effective years.

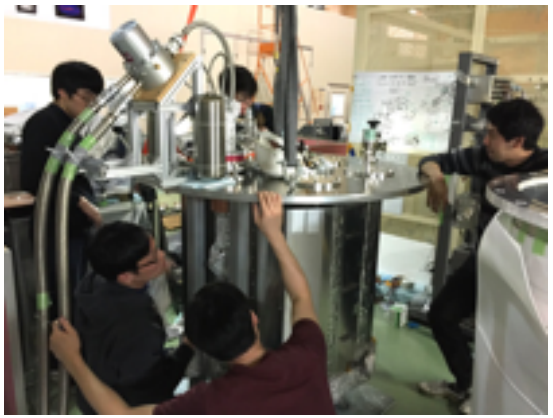


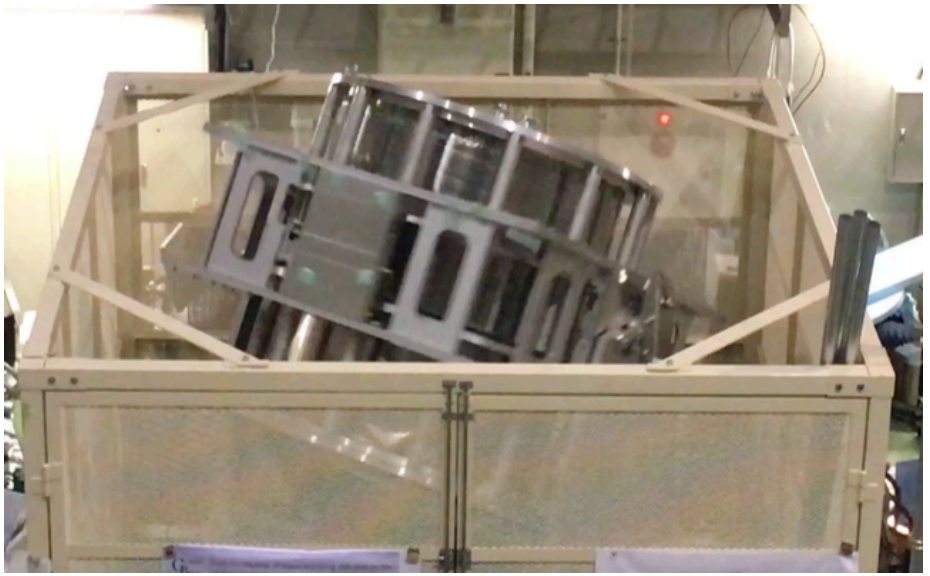


GroundBIRD

- Japan (KEK, Riken, NAOJ, Universities of Tohoku, Saitama, Tokyo and Kyoto), Korea (University of Korea, IBS), Spain (IAC), the Netherlands (TU Delft)
- Formal Agreement signed on 14 Dec 2016.
- At Teide observatory, at a former VSA enclosure (possible future extension to Atacama)
- Planned installation: autumn 2018.
- Operation plan: 3 years (2018-2020)

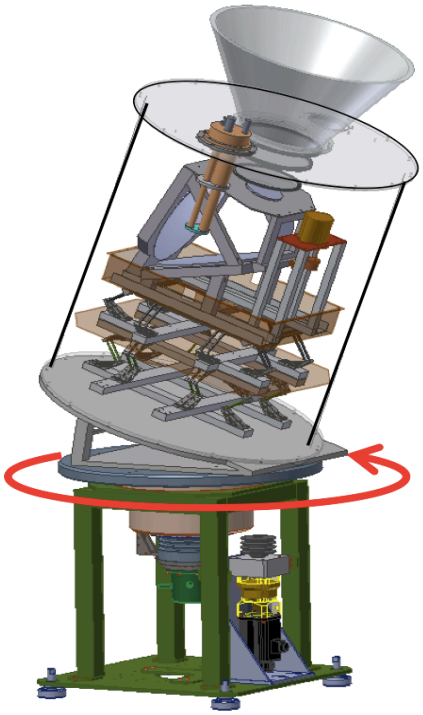


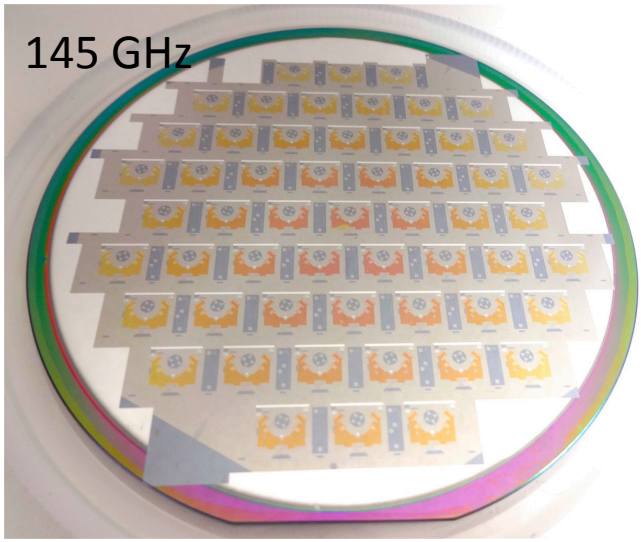


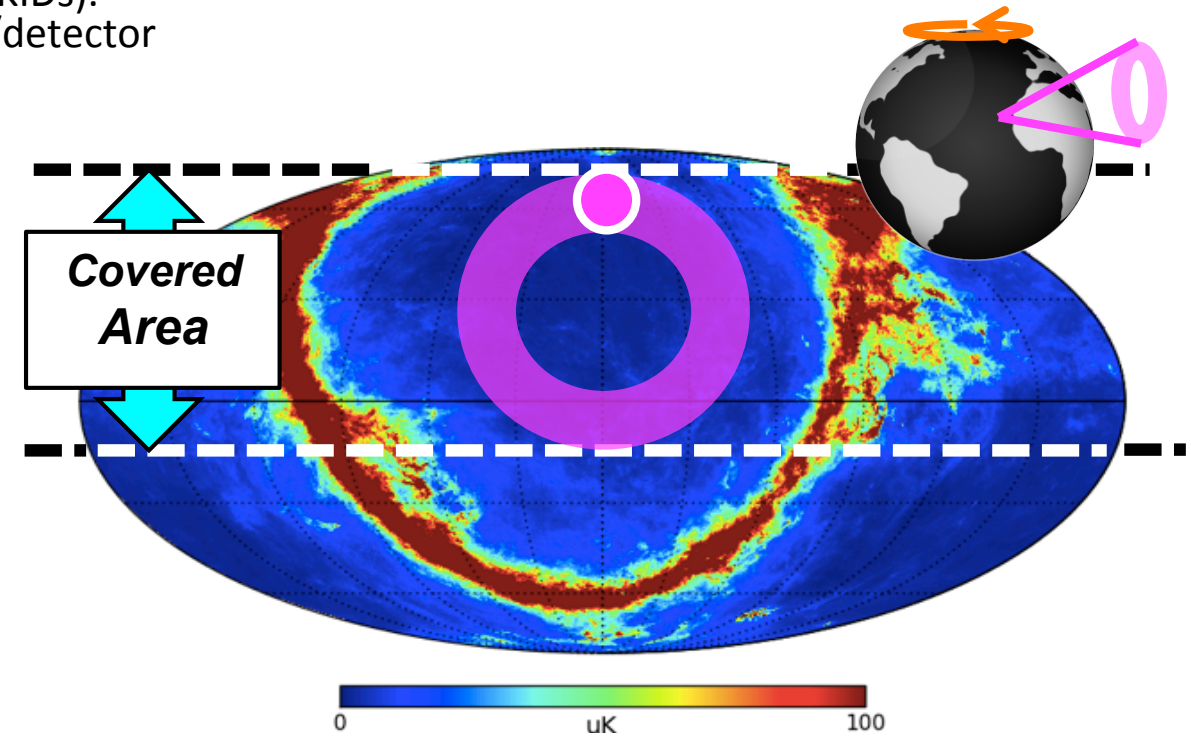


GroundBIRD

- Large angular scales (fsky=0.5) and coarse angular resolution (FWHM = of 0.6 deg @ 145 GHz), with a 20 deg FOV
- High-speed AZ scans (20 rpm) to reduce the atmospheric noise
- AZ scans + Earth rotation provides very large-scale fields
- KIDs fast response well matched with the high rotation speed
- 145 GHz (660 KIDs) and 220 GHz (224 KIDs). Expected sensitivity: 300 muK*sqrt(s)/detector (including the atmosphere)



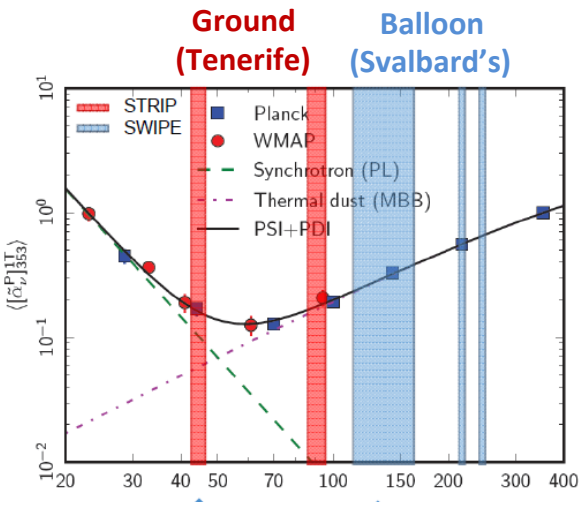




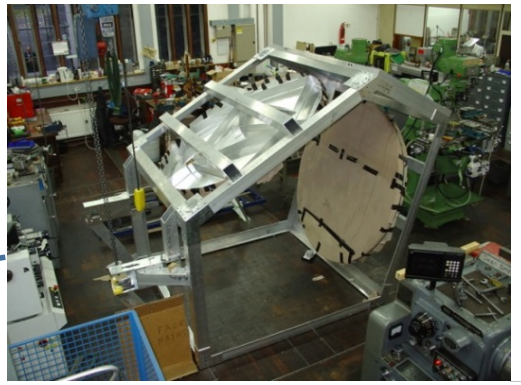
LSPE/STRIP

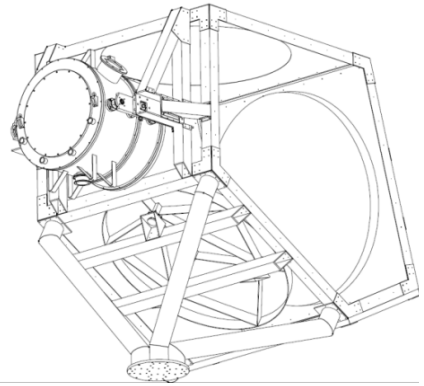
Q and W band polarimeter array

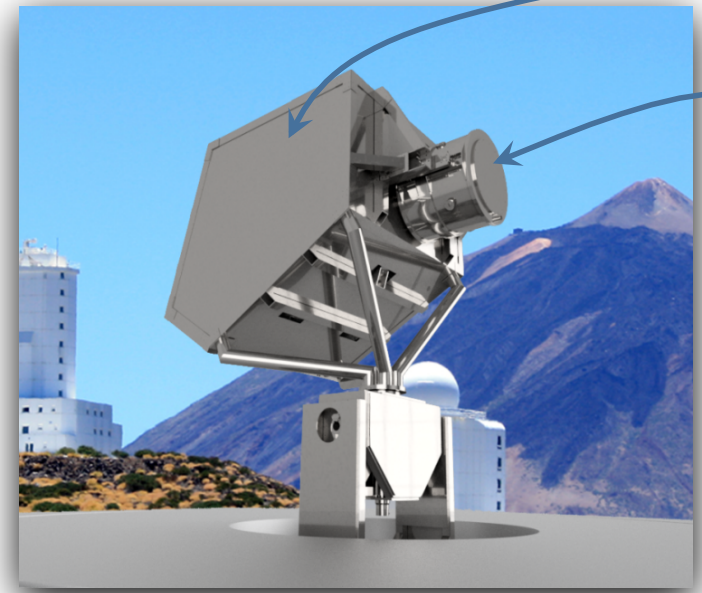
25% sky coverage



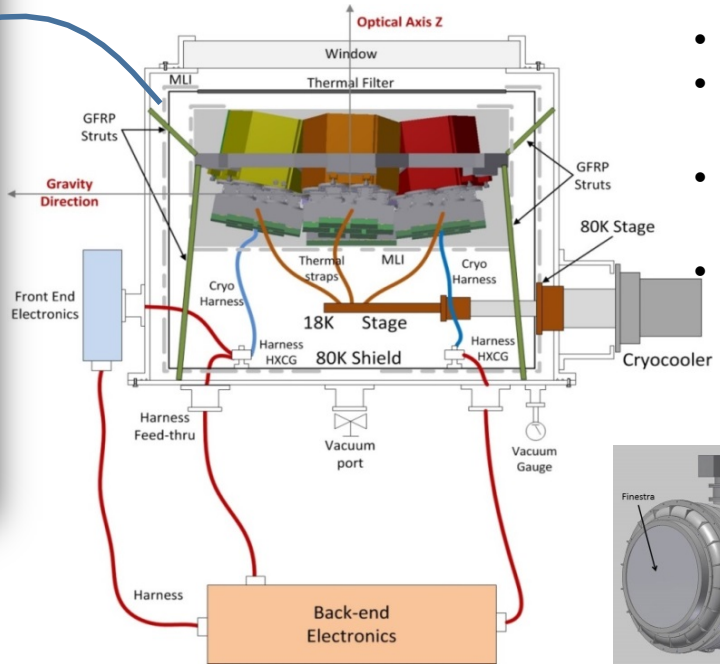
1.5m cross-Dragone telescope (Oxford University)



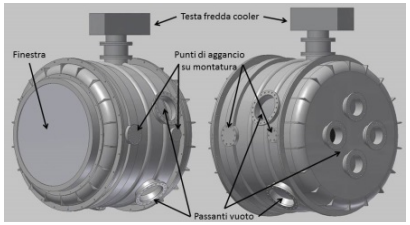




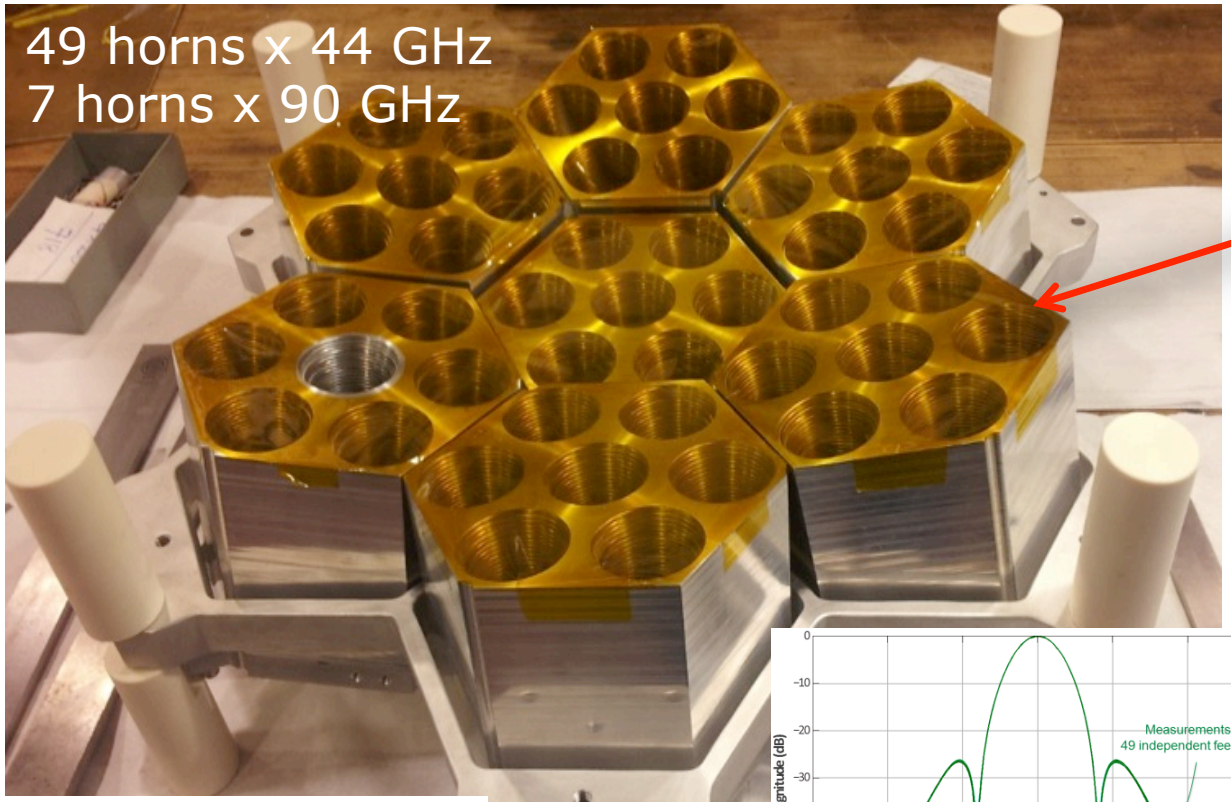
Deployment at Teide Observatory
foreseen in Spring 2018

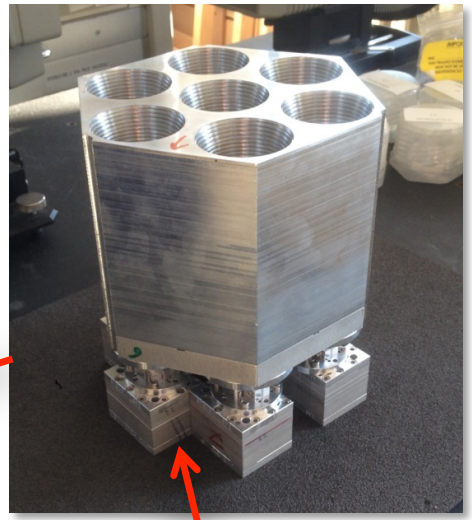


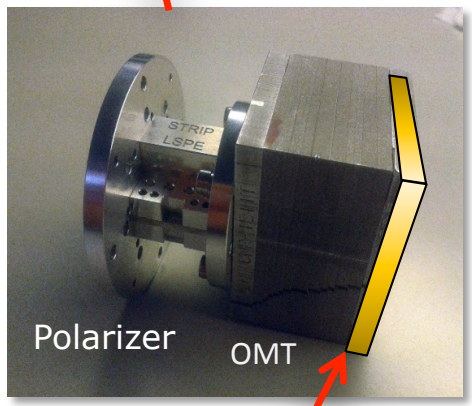
- High efficiency 2-stage cooler
- Intermediate 80-100K shield reducing load on 18-20K stage
- Accurate parasitic heat leaks control
- System designed withstand all possible orientations, rotating ±70°from vertical around elevation axis

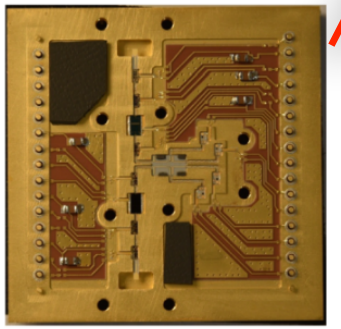


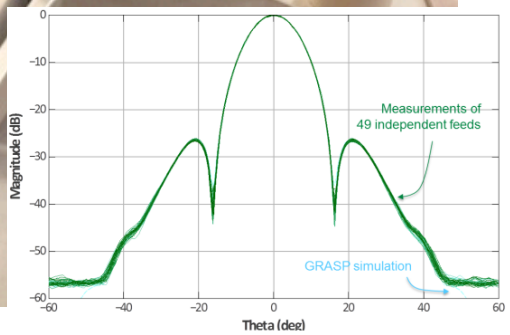
LSPE/STRIP
Focal plane











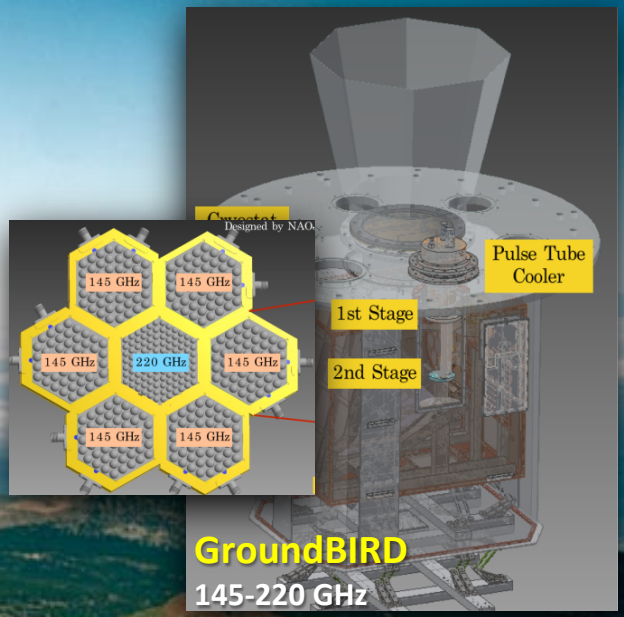
State-of-the-art platelet technique

- *Match with EM model to -55dB*
- *Excellent performance* for *cross-pol down to -40dB*

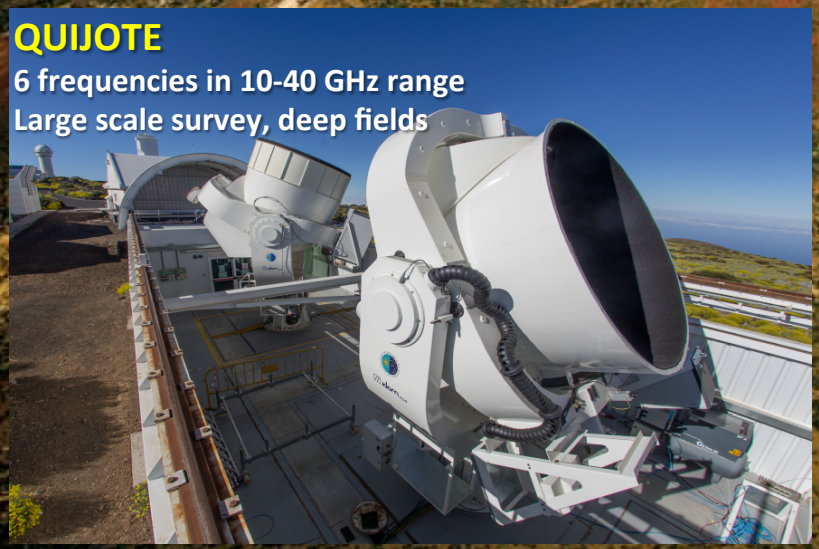
Polarimeter

Teide Observatory (Tenerife)

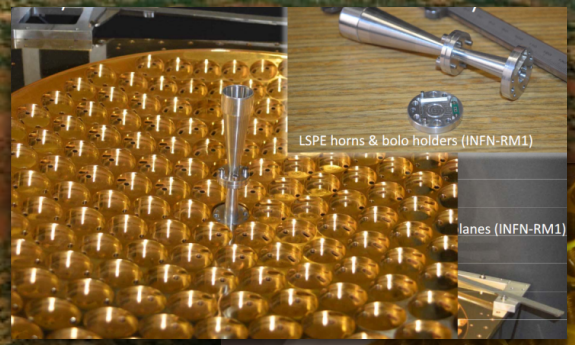
Same sky area (>20% sky, North Hemisphere)
10 frequencies from 10 to 240 GHz
Redundancy, cross-correlation



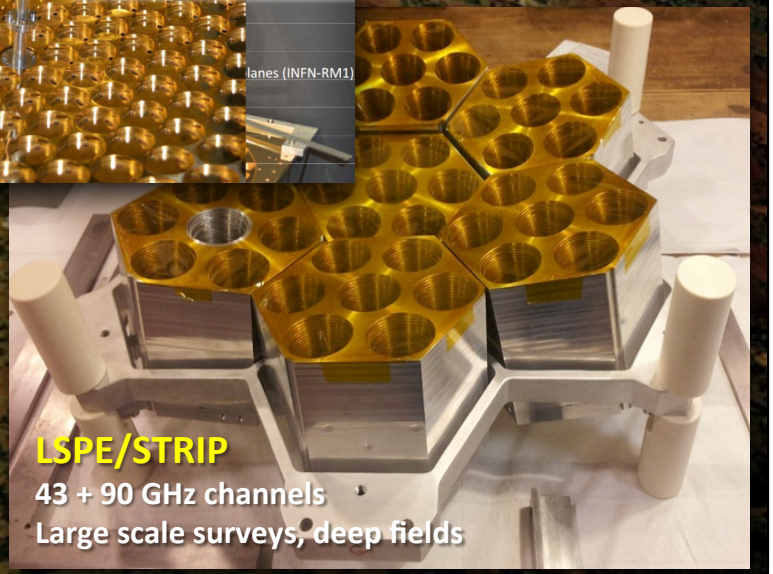
GroundBIRD
145-220 GHz



QUIJOTE
6 frequencies in 10-40 GHz range
Large scale survey, deep fields



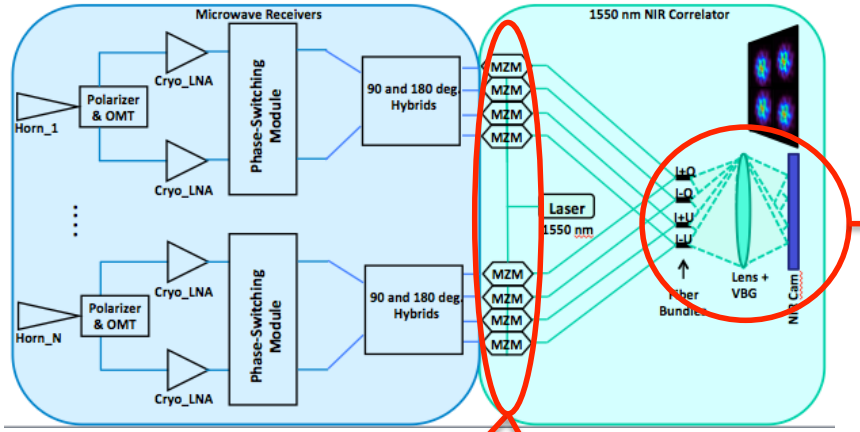
LSPE/SWIPE
140-220-240GHz

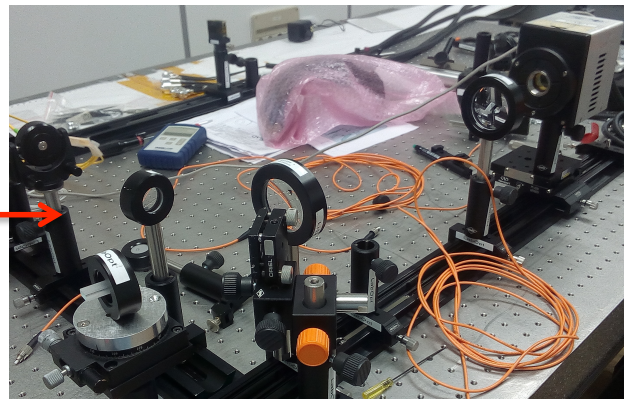


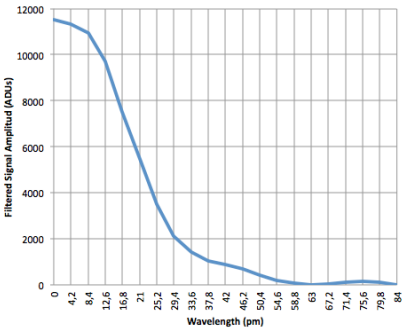
LSPE/STRIP
43 + 90 GHz channels
Large scale surveys, deep fields

Plans for a Large Format Interferometer with Optical Correlator.

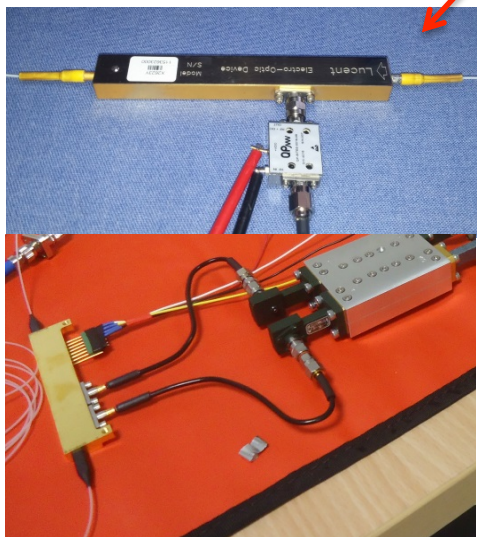
- A preliminar study done within the Spanish EPI Consolider project.
- The technological demonstration and fabrication of a prototype of a few elements already funded by two Spanish national projects.

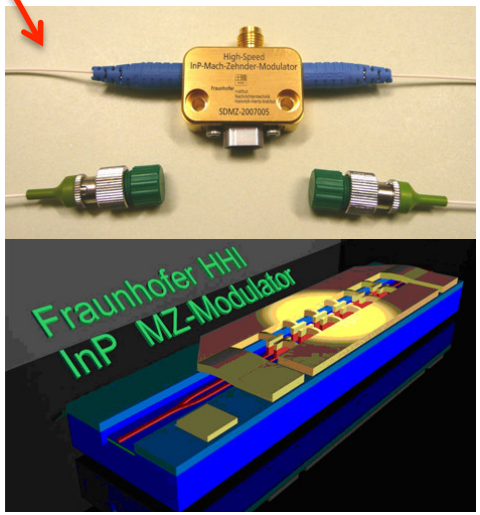




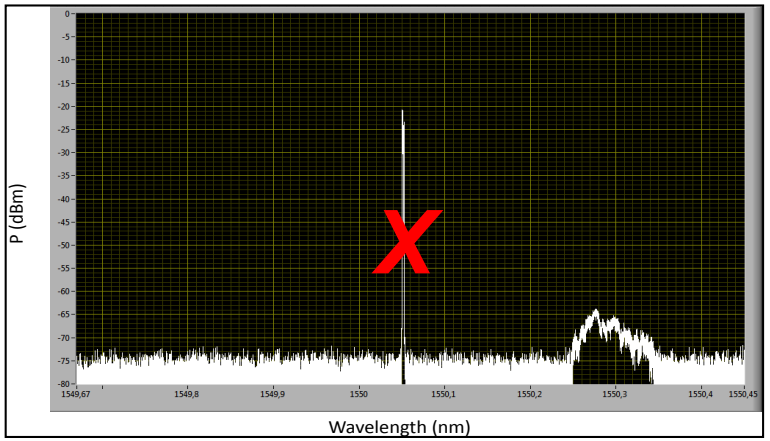


Up-conversion of MW Signals to the IR





NIR Optical Filtering and Correlation

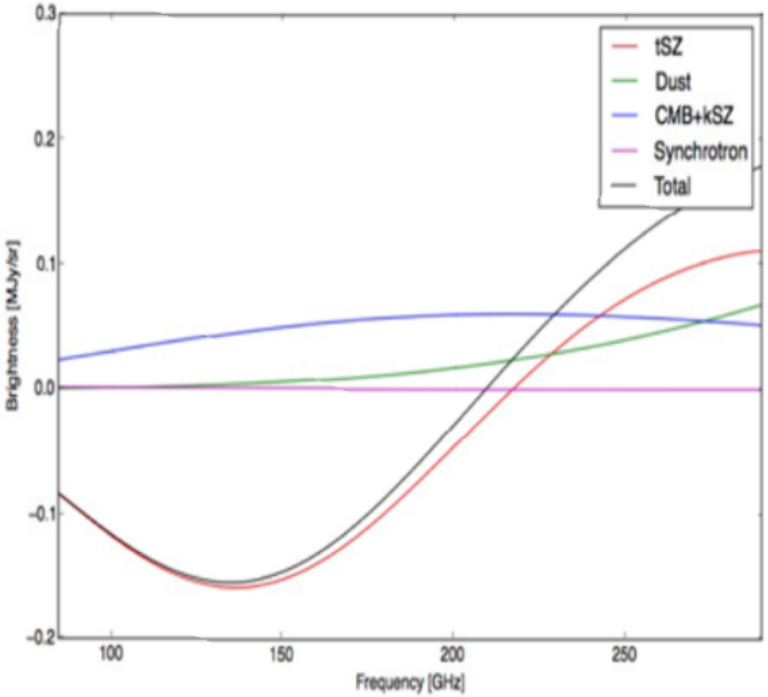


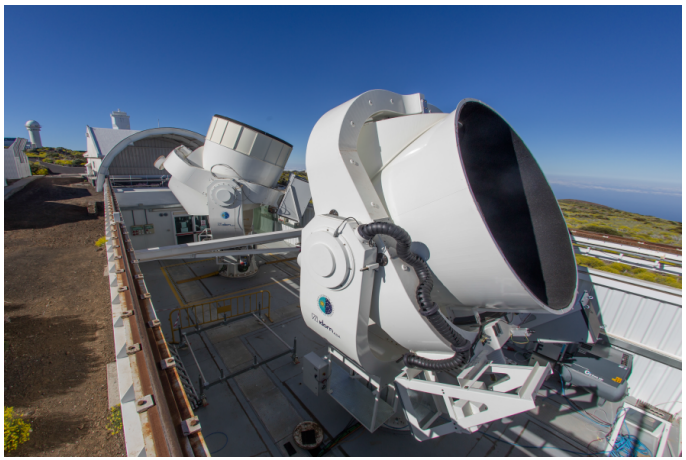
KISS KID Imager-Spectrometer Survey

Grenoble (Institut Néel, LPSC, & IPAG), Tenerife (IAC) & Roma (La Sapienza)

Scientific motivation and concept

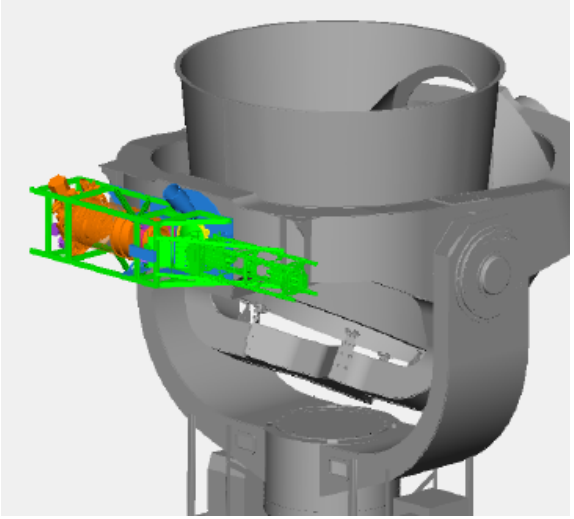
- Use low resolution spectroscopy to separate different components in the millimeter emission of clusters.
- Map low redshift clusters physical properties from their SZ spectral distorsions : pressure (tSZ), temperature (RtSZ), LOS velocity (kSZ)



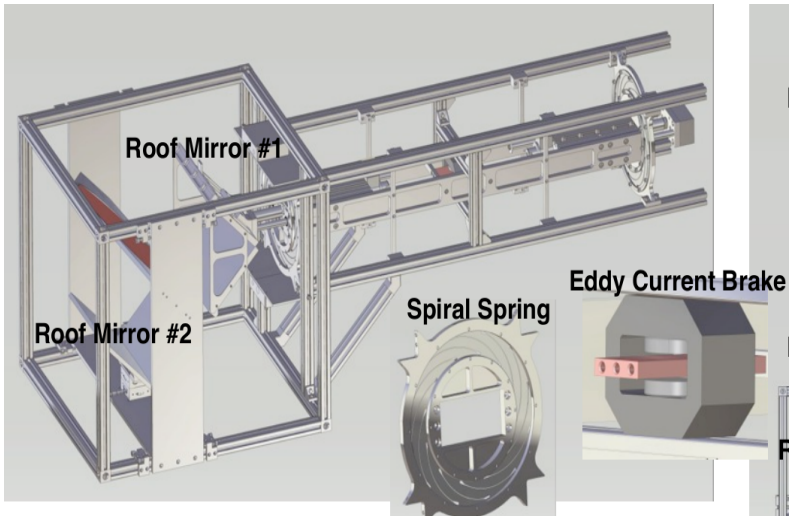


KISS : Low-resolution (Δν = 1-3 GHz) Martin-Puplett interferometer (MPI) coupled to a KID based camera (100-300 GHz) mounted at one of the QUIJOTE telescopes (2.25 m diameter) in the Teide Observatory.

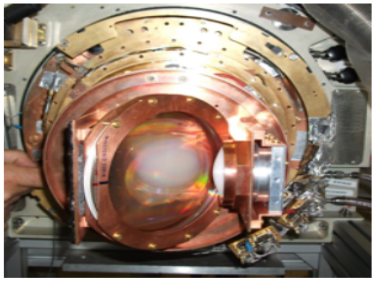
Instrument design and status



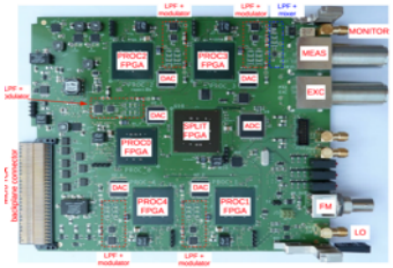
- MPI has been built, currently under test at Grenoble labs.
- NIKA camera has been adapted for KISS optical design
- Large frequency band (80-300 GHz) 500 KID arrays has been constructed
- Readout electronic ready for use

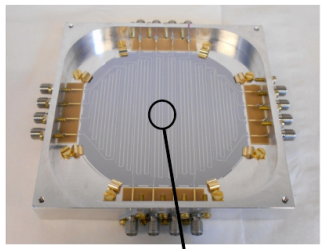


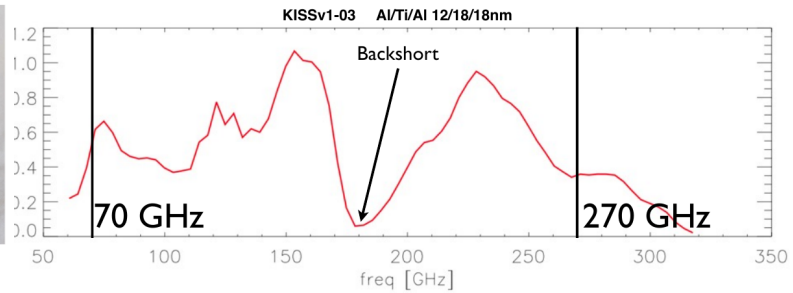
Dilution Cryostat 3He-4He (100 mK)



Frequency Multiplexing Read-Out Electronics : NIKEL

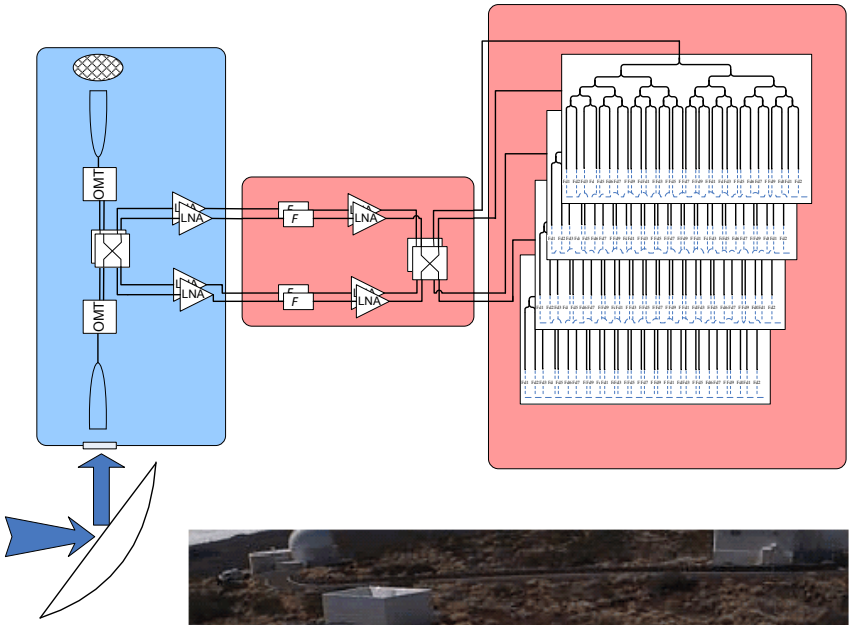


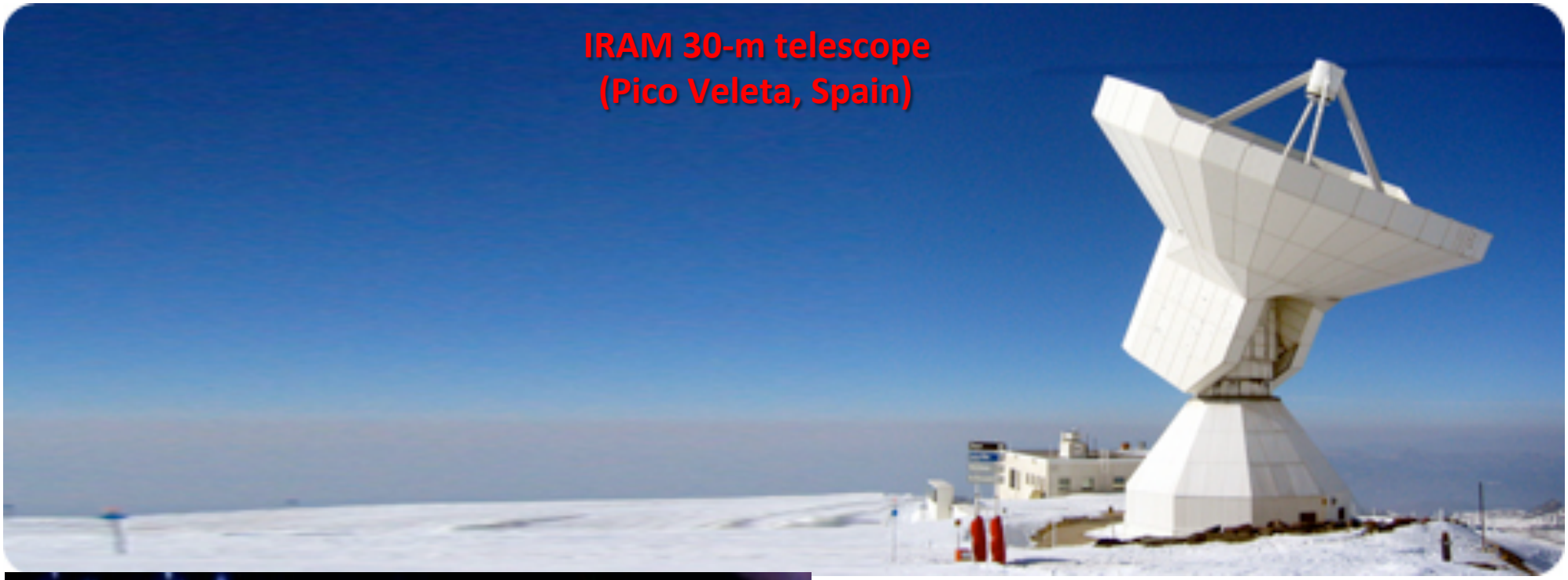


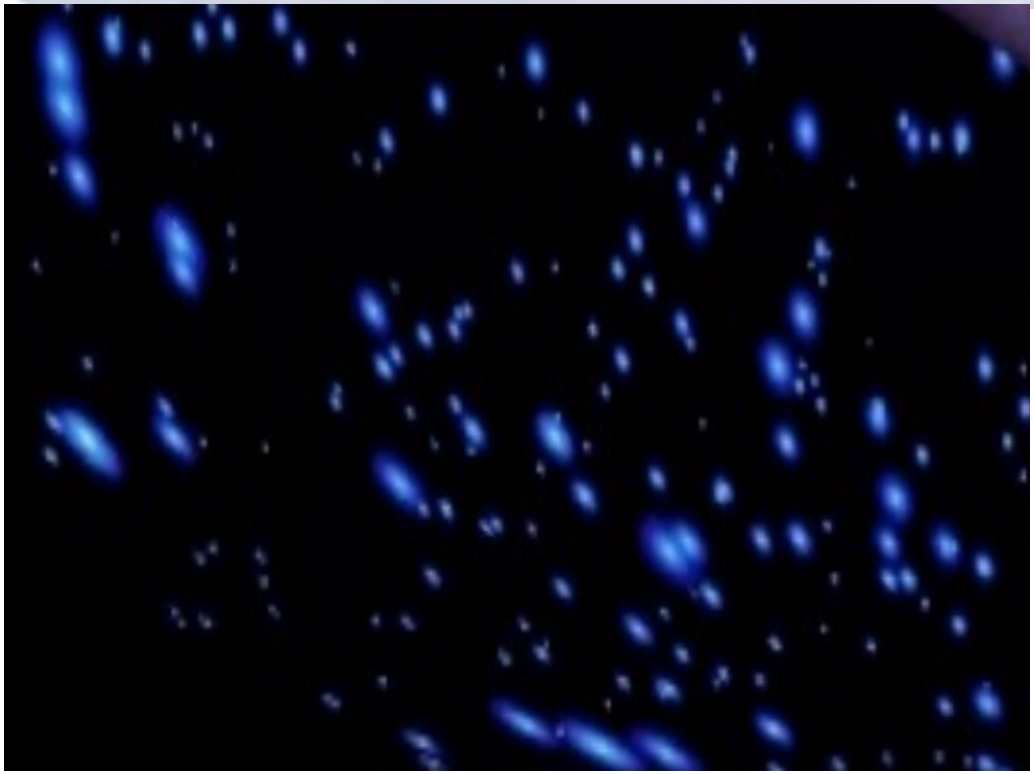


Microwave Spectrometer in the 10-20GHz band

- IAC project. Already funded.
- **Science driver**: Ground-based low resolution spectroscopy observations in the 10-20GHz range to characterize foregrounds (monopole signals; spectral dependence of monopole signals; ARCADE results) and CMB spectral distortions. Provides frequency cross-calibration for QUIJOTE.
- **Proposed instrument**:
  - FEM cooled to 4-10K (HEMTs), reference load to 4K.
  - Novel FTS spectrometer providing √N increase in sensitivity with wideband simultaneous adquisition.
  - ~2deg beam, 0.25 GHz spectral resolution (40 bands).
- **Timescale**: two years. Now in final design phase.
- **Location**: Teide Observatory (former VSA enclosure).







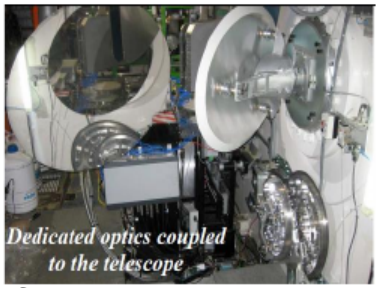
NIKA2

A millimeter camera for cluster cosmology

The NIKA2 camera

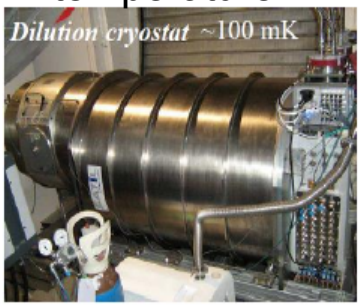
Dual band mm KID camera operating and 150 and 260 GHz

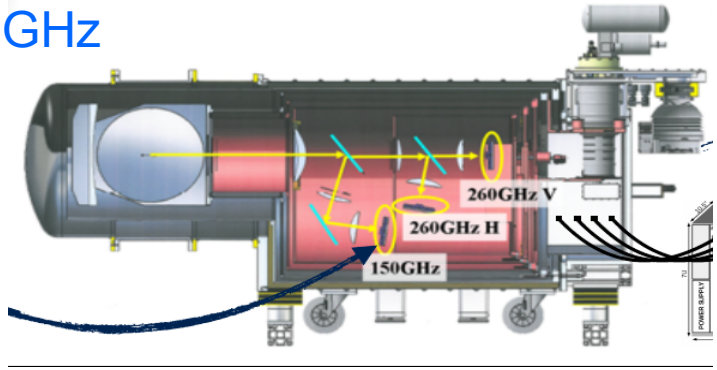
IRAM 30-m telescope
at Pico Veleta (Spain)



Specific optical system
to obtain the largest
FOV

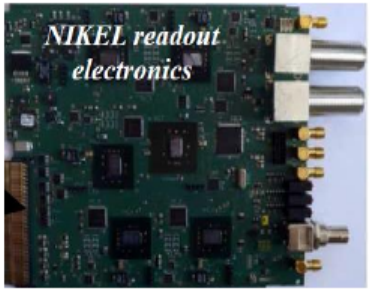
Dilution cryostat:
180 mK nominal
temperature





Arrays of 1140 (616) KIDs:
8 (4) independent feedlines
with up to 200 KID each

300 multiplexing factor



20 boxes (one per feedline)
arranged in 3 crates (one
per array)

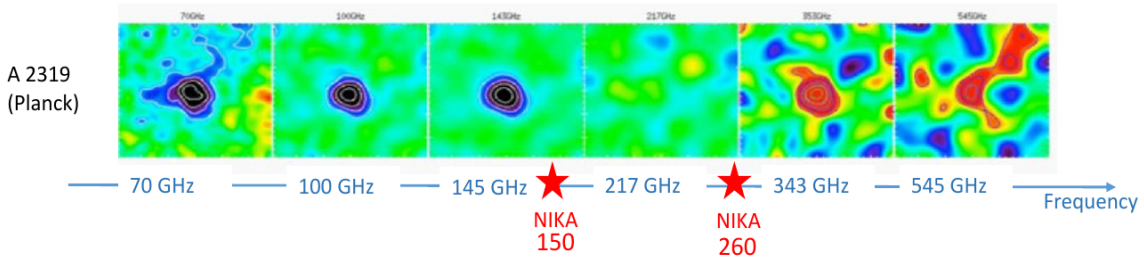
The NIKA2 camera

- September 2015 : installation at IRAM.
- October 2015 : First light
- September 2016 : complete instrumental setup
- April 2017 : commissioning succesfully finished ; performance better than expected.
- Open to for public observations for at least one decade from now.

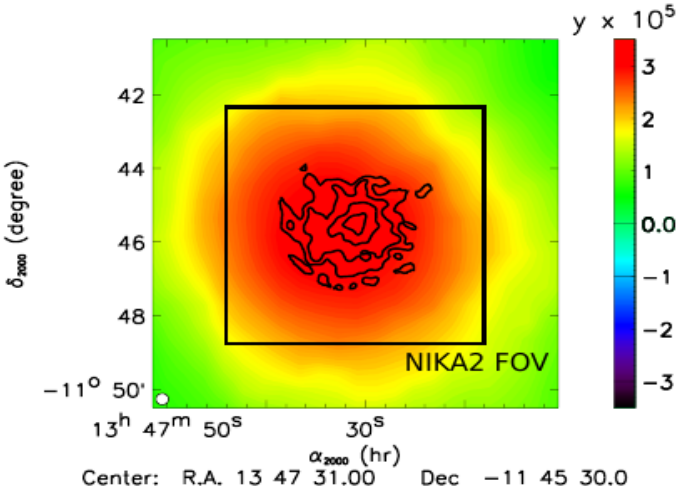
Frequency	150 GHz	260 GHz
# KIDs	616 (553)	2 x 1140 (960)
FOV diameter	6.5 arcmin	6.5 arcmin
Sensitivity	6 mJy/s$^{1/2}$	20 mJy/s$^{1/2}$
Angular res.	17.7 arcsec	11.2 arcsec

[NIKA collaboration, A&A, 2017,arXiv:]

NIKA2 is well adapted for SZ observations of intermediate and high redshift clusters



- Two frequency bands, negative & zero tSZ signal
- Large FOV : size of PLANCK beam
- High resolution : 17 times better than Planck



One of the 5 NIKA2 LP (300h) devoted to tSZ. **50 high redshift clusters 0.5 < z < 1.0.**

Dome Concordia (Antarctic plateau)

Concordia station:

- 75° 06’ S – 123° 21’ E, 3233 m
- <T>=-50° ; min(T)=-85°

High altitude but fully logistical supported. 16 crew-members during winter. Maximum 80 people during summer

Diffusely site tested at all wavelengths and continuous atmospheric monitoring.

Water Vapour Content ~75% of the time below 0.4mm PWV (*Tremblin et al., 448 A65 A&A 2012*)

Circular and linear polarizations constrained to

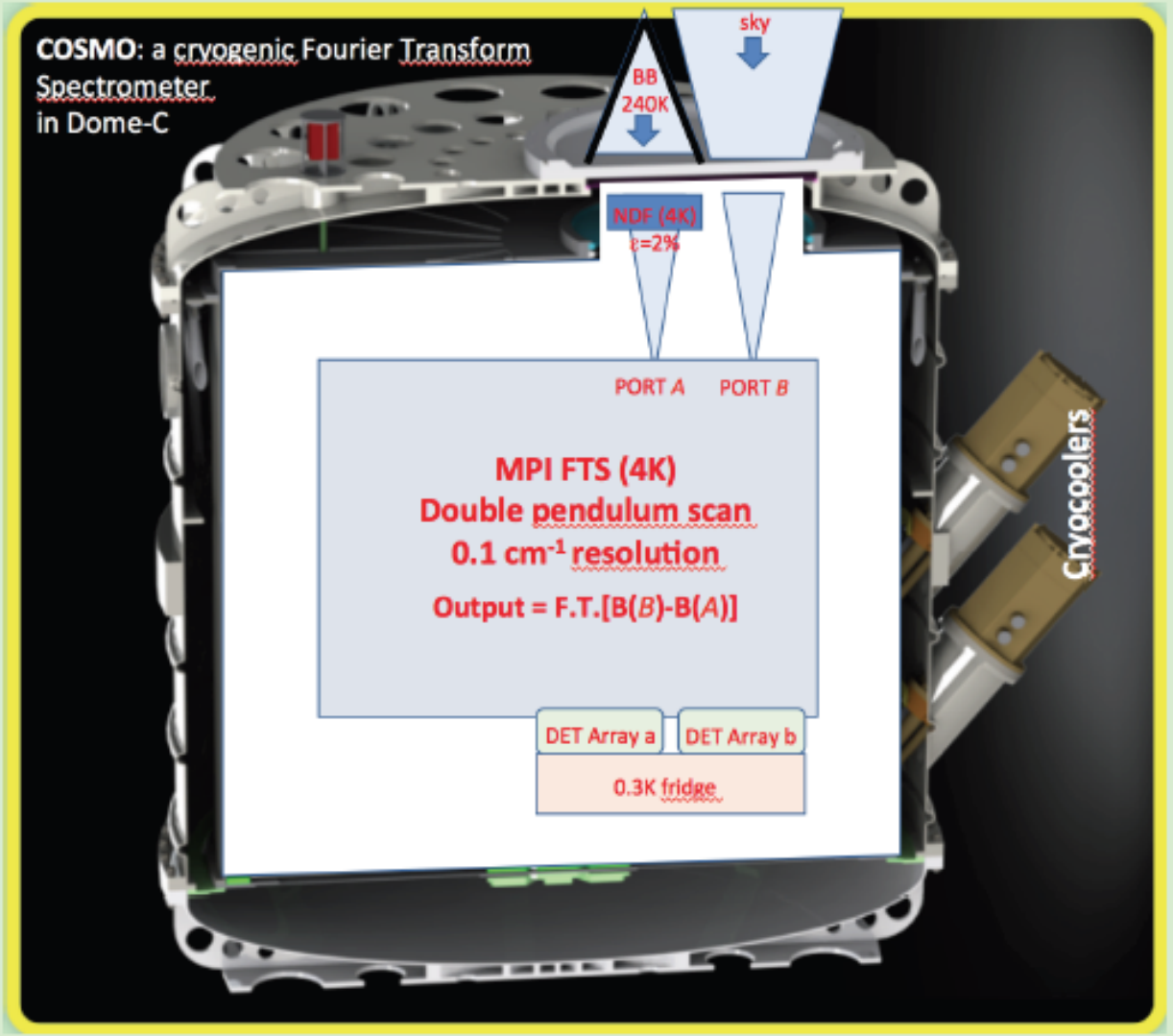
- CP<0.19%;
- LP<0.11% (*Battistelli et al., 423 1293 MNRAS 2012*)

COSmological Monopole Observer (COSMO) at DOME C

- Double cryogenic FTS measuring the spectrum of the difference between the sky and a reference BB:

$$S(\vec{\theta},\nu) = A\Omega[B_{sky}(\vec{\theta},\nu) - \varepsilon \cdot BB(T,\nu)]$$

- Moderate (3GHz), and adjustable frequency resolution within 30GHz around 150GHz
- 2 x 64 pixel (prototype) → 2 x 1000 pixels (final instrument) KIDs arrays
- No external optics
- Large dry cryostat, necessary for operations in Concordia (cryocooler operation has been diffusely tested in Concordia with to the BRAIN-pathfinder experiment (*Battistelli et al. MNRAS, 2012*)



SAPIENZA UNIVERSITÀ DI ROMA · UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA · CNR IFN Istituto di Fotonica e Nanotecnologie · CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD · ASU ARIZONA STATE UNIVERSITY

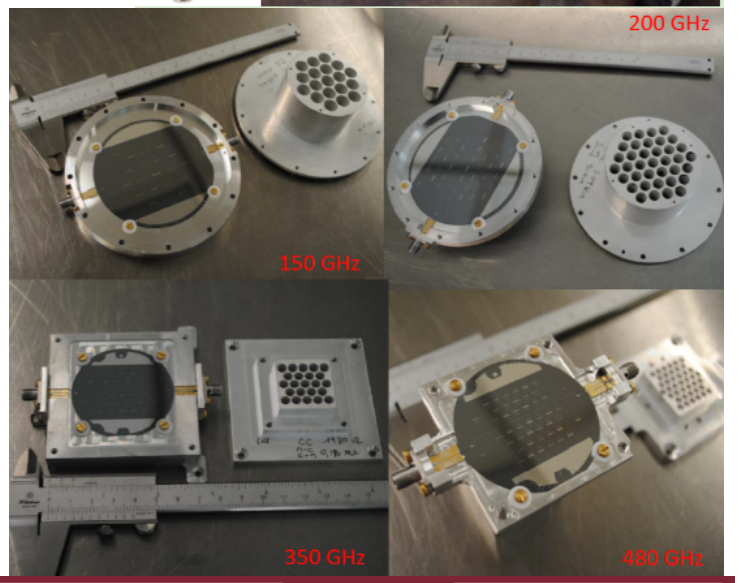
COSmological Monopole Observer (COSMO) at DOME C

Cryostat and mount

- Large cryostat (with 1 m^3 at 3K) directly looking at the sky with no warm focussing optics.
- The instrument will be installed in a warmed up insulated shelter (with a hole on the ceiling). They will re-use of the compressor PT heating.
- 2 x cryomechanic pulse tube refrigerators
- Ground shields and forebaffle

Detectors: KIDS.

- Development and optimization Kinetic Inductance Detectors specifically for millimetric (i.e. CMB) observations from Concordia.
- Examples of KIDs array developed at Sapienza University (in collaboration with the IFN-CNR): OLIMPO 150GHz, 220GHz, 350GHz, 480GHz arrays.



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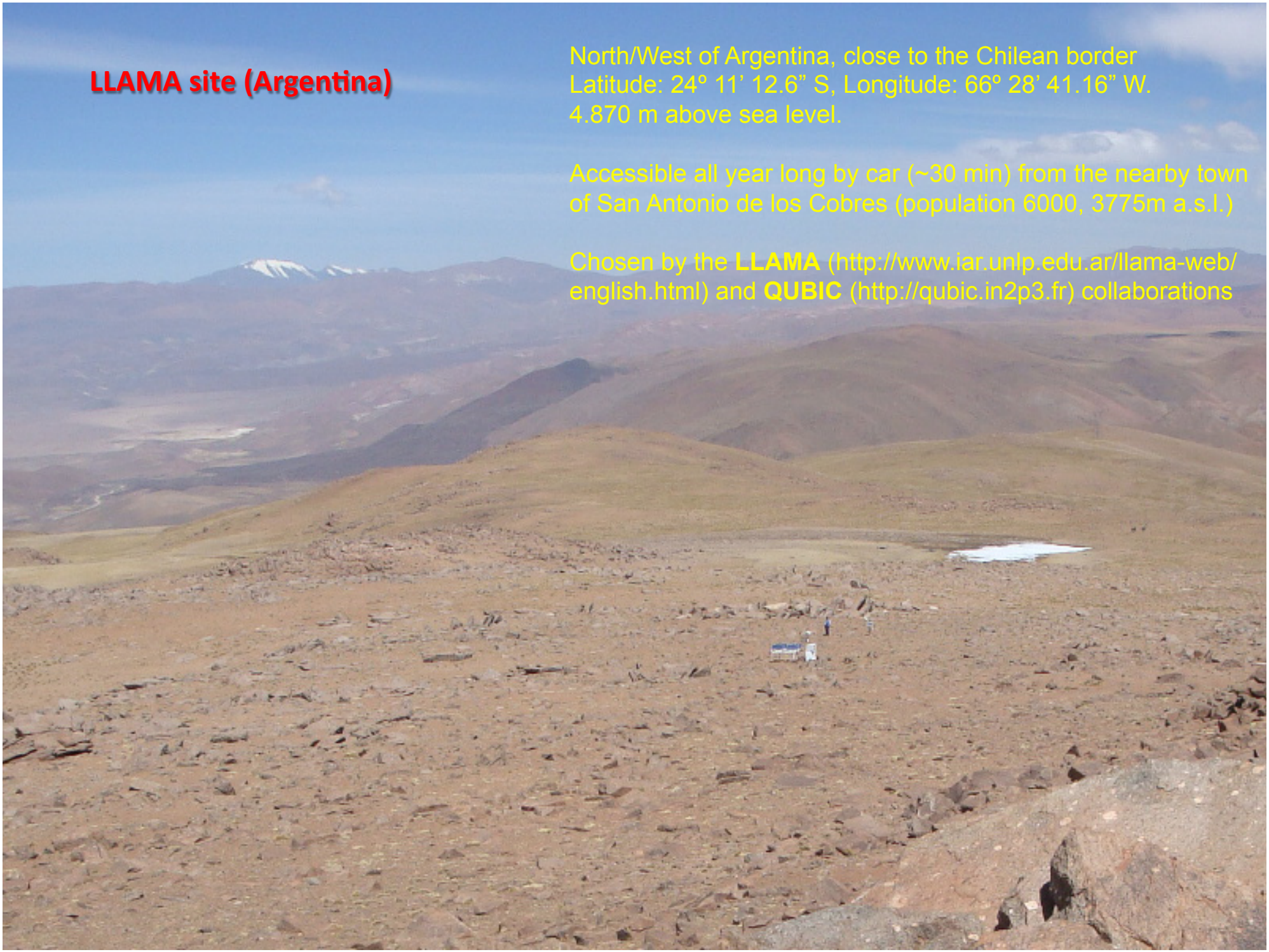

LLAMA site (Argentina)
North/West of Argentina, close to the Chilean border
Latitude: 24º 11' 12.6" S, Longitude: 66º 28' 41.16" W.
4.870 m above sea level.
Accessible all year long by car (~30 min) from the nearby town of San Antonio de los Cobres (population 6000, 3775m a.s.l.)
Chosen by the **LLAMA** (http://www.iar.unlp.edu.ar/llama-web/english.html) and **QUBIC** (http://qubic.in2p3.fr) collaborations

Q U Bolometric Interferometer for Cosmology

TES focal planes

- 2048 TES with NEP ~ $4x10^{-17}$ $W.Hz^{-1/2}$
- 128:1 SQUIDs+ASIC Mux Readout

400 elements bolometric interferometer

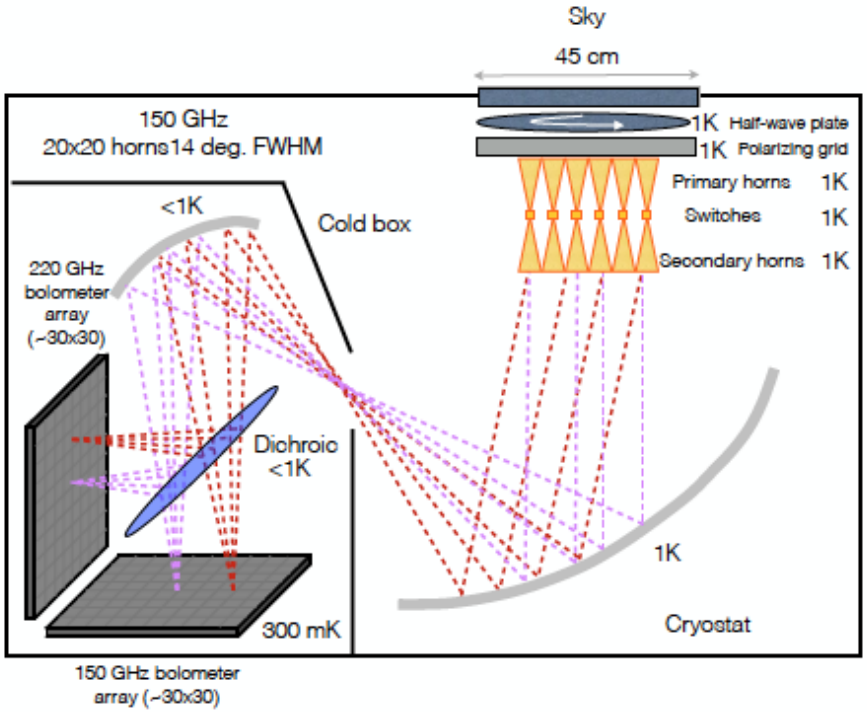
- Synthesized imaging on focal planes
- 23.5 arcmin FWHM

Dual Band operations

- One focal plane for each band
- 150 and 220 GHz

Switches on each horn

- Ability to reconstruct baselines individually
- Self-Calibration like an interferometer



Schedule….toward the primordial B-modes search

- **2016: Focal Plane testing**
  - -256 TES in Lab Cryostat
  - -128:1 Multiplexing

→ Validation of Detection Chain 

- **end 2017: Technological demonstrator**
  - -Nominal cryostat
  - -8x8 horns array
  - -reduced mirrors
  - -256 TES
  - -Laboratory testing in Paris

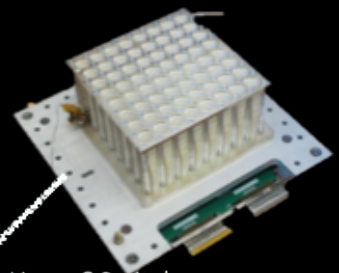
→ Validation of technology 

- **end 218: 1st Module in Argentina**
  - -400 horns array

→ B-mode target
$\sigma(r) = 0.01$ in 2 years

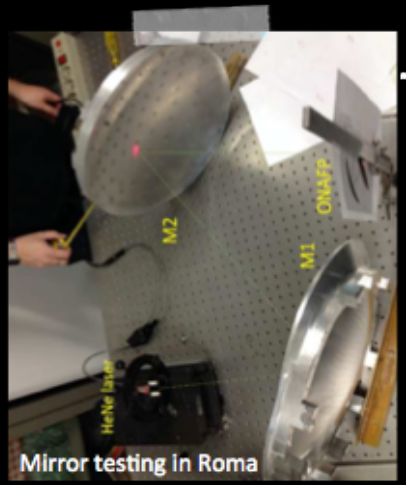
Technological Demonstrator Status

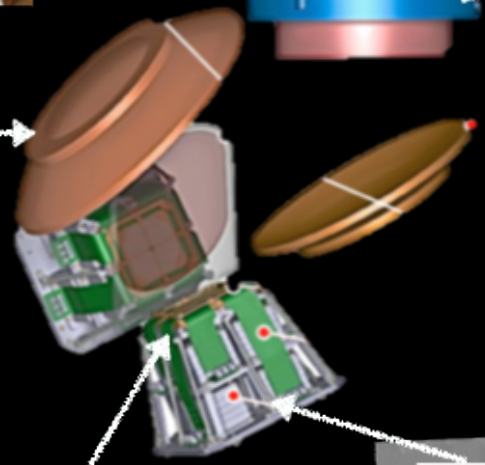
The instrument is being integrated



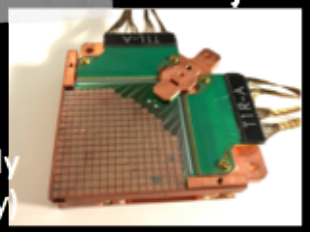
Horns&Switches
(Milano)

Cryostat@Roma

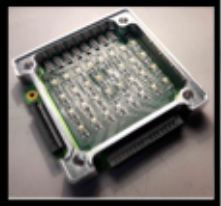




Calibration mount
(LAL/Orsay)

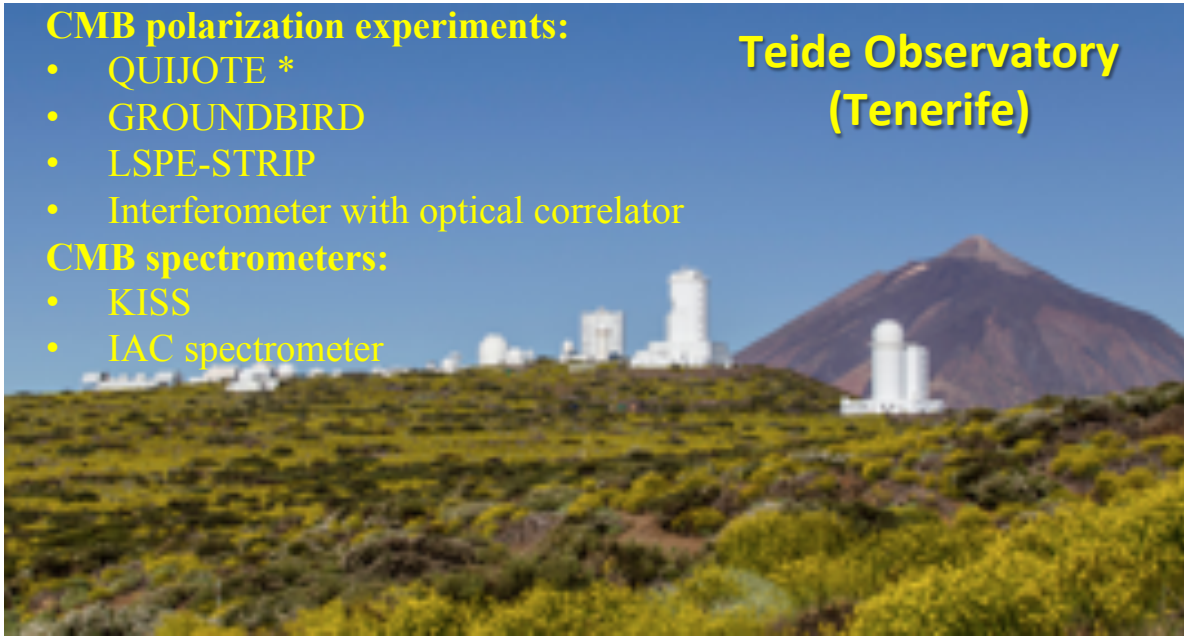


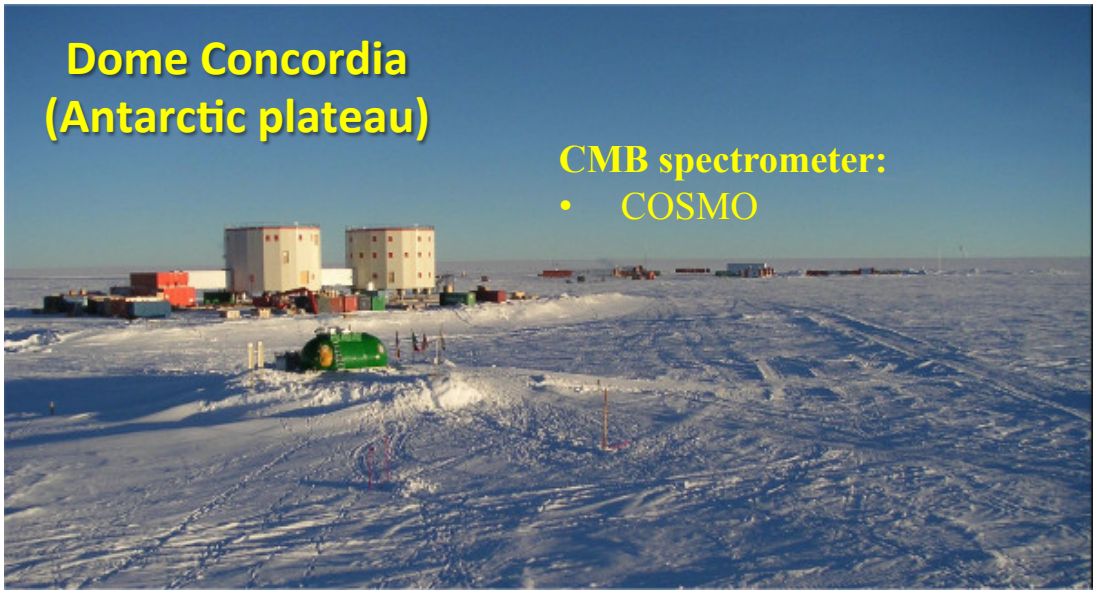
TES array ready
(CSNSM/Orsay)



Squid Board
+ ASIC (APC/Paris)

CMB experiments at European sites



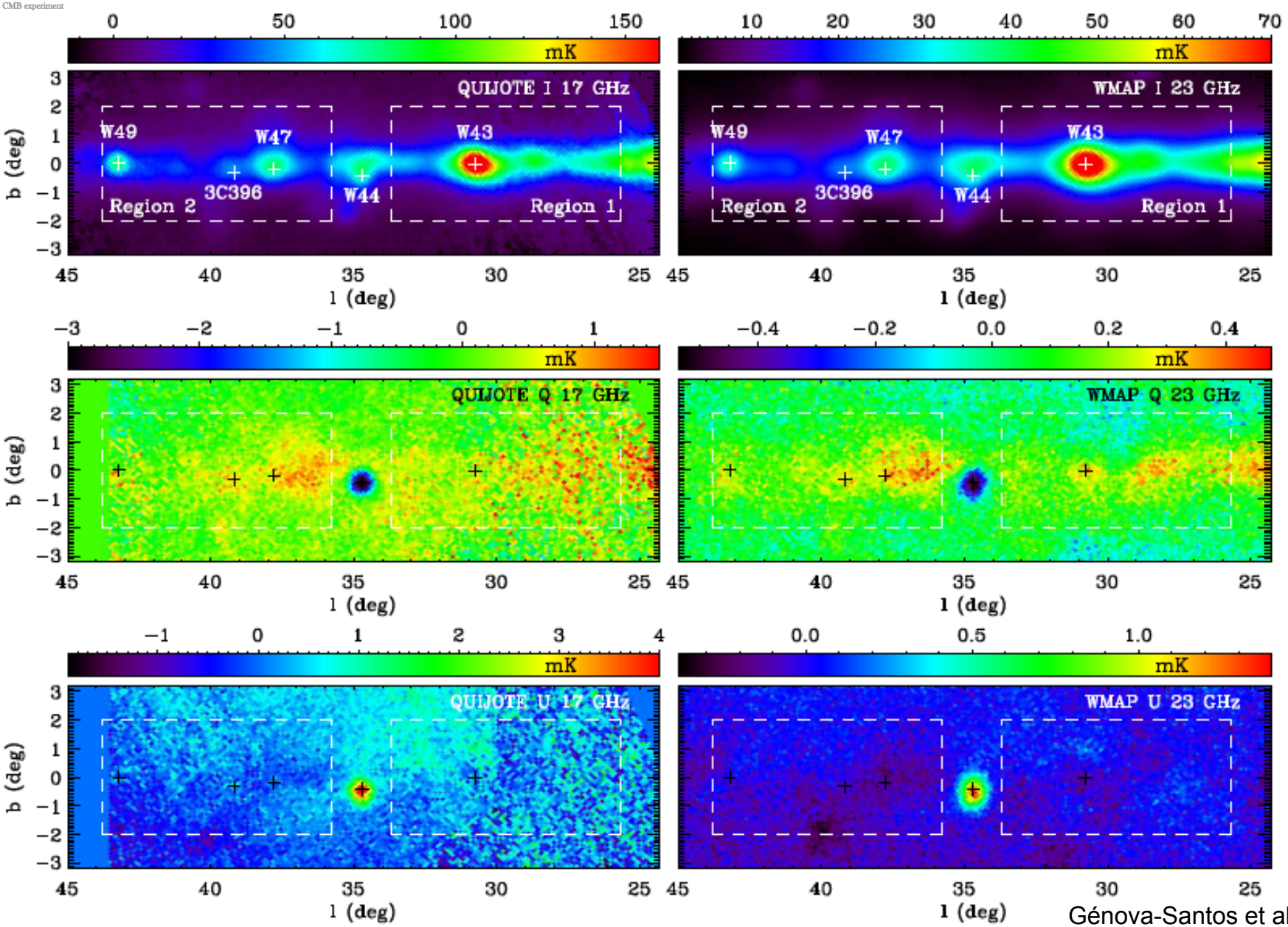


(* = in operation)

Extra slides

W43, W44 and W47 (25º<l<45º)

(W44 is a bright SNR. Both W43 and W47 are molecular complexes)



Génova-Santos et al. (2017)

W43, W44 and W47 (25º<l<45º)

★ Fits to intensity SEDs

★ Fit AME with the a 3-parameter parabola:

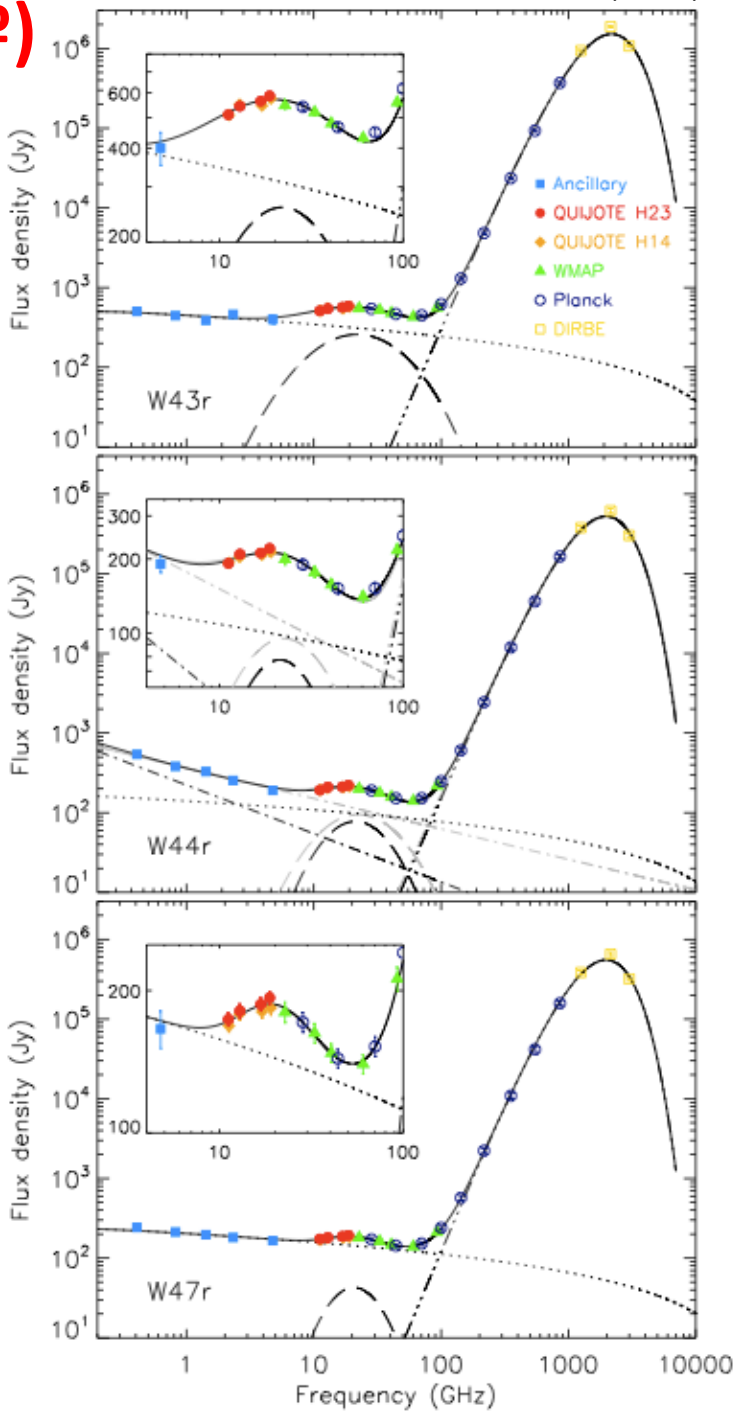
Region	S_{AME} (Jy)	*EM* (cm^{-6} pc)	χ^2/dof
W43	258 ± 7	3911 ± 68	5.4
W44	78 ± 6	1264 ± 22	1.0
W47	43 ± 2	1849 ± 20	1.0

★ *EM* estimates from Commander or from RRL (Alves et al. 2015):

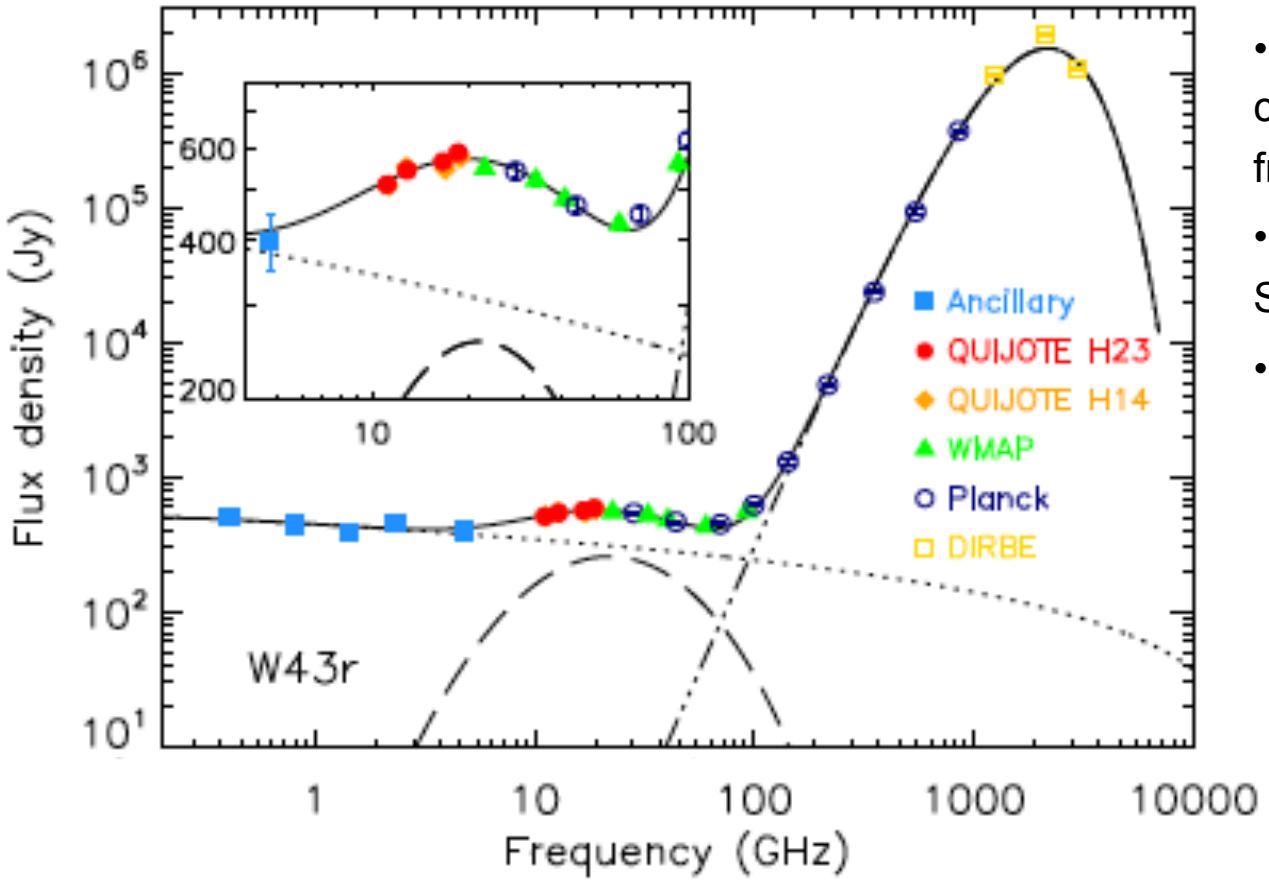
Region	Commander	RRL
W43	5888	4020 - 6190
W44	1667	990 - 1340
W47	1806	1360 - 1840

Commander seems to overestimate the free-free and underestimate the AME

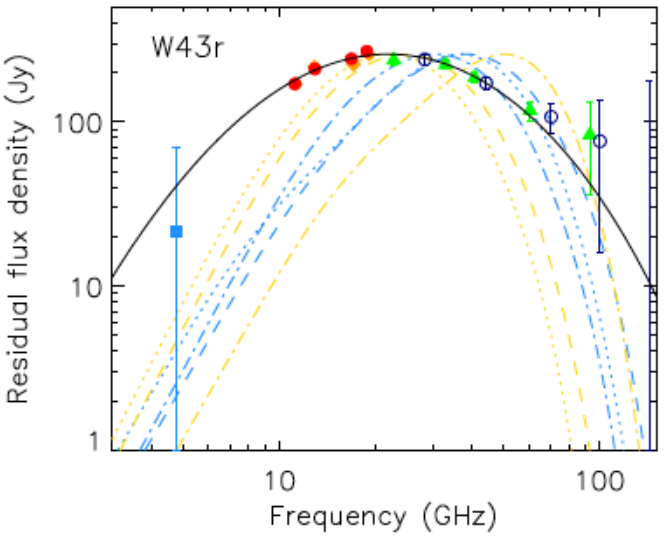
Génova-Santos et al. (2016)



W43 molecular complex



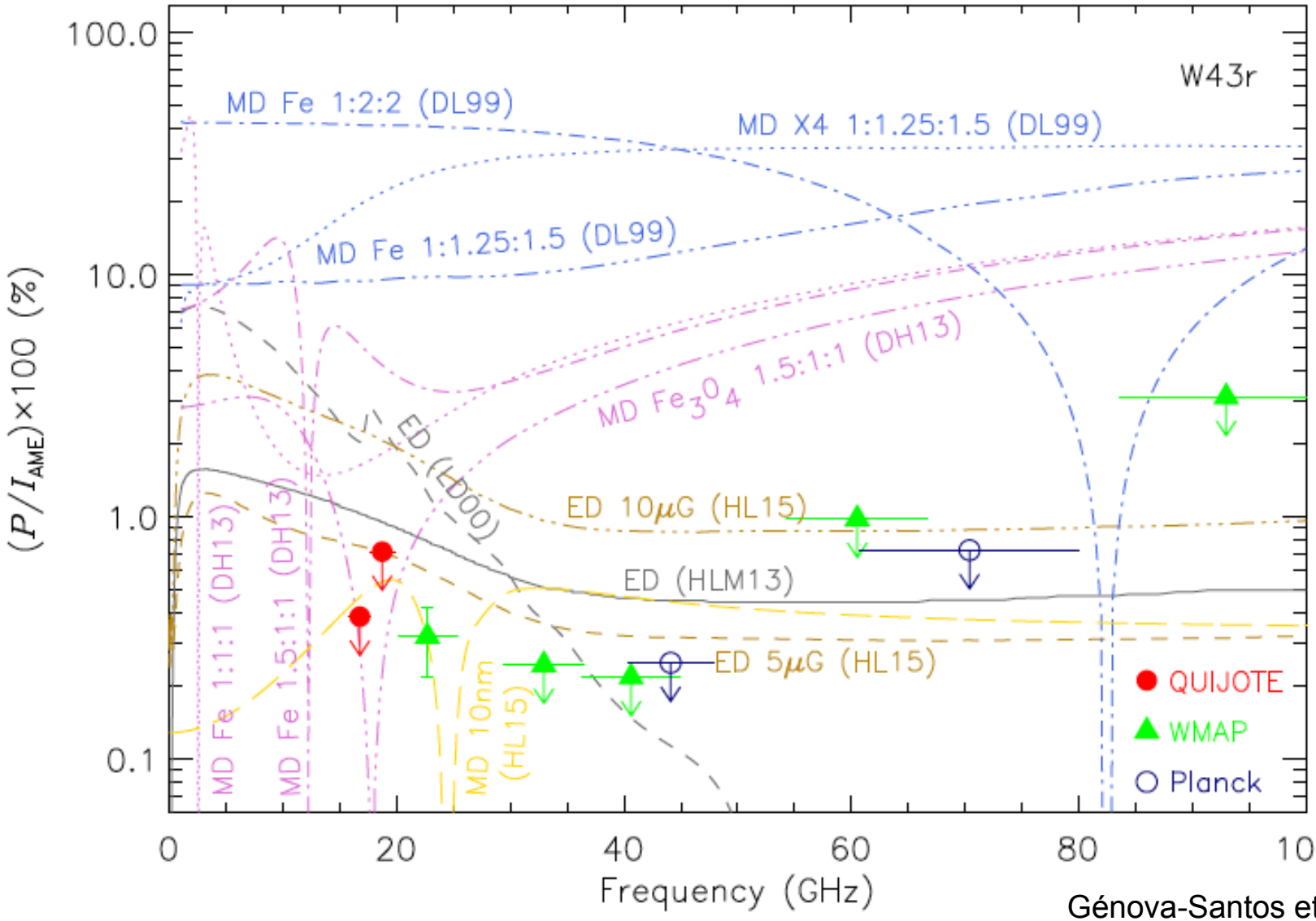
- The four QUIJOTE data points confirm the downturn at low-frequencies due to spinning dust.
- Free-free dominated intensity SED.
- AME peak brighter than Perseus.



Génova-Santos et al. (2017), MNRAS submitted, arXiv:1605.04741.

W43 molecular complex

Constraints on AME polarization fraction and comparison with ED models. Best upper limits to date (< 0.4% at 17GHz from QUIJOTE, and < 0.22% at 23GHz from WMAP).



Génova-Santos et al. (2017)

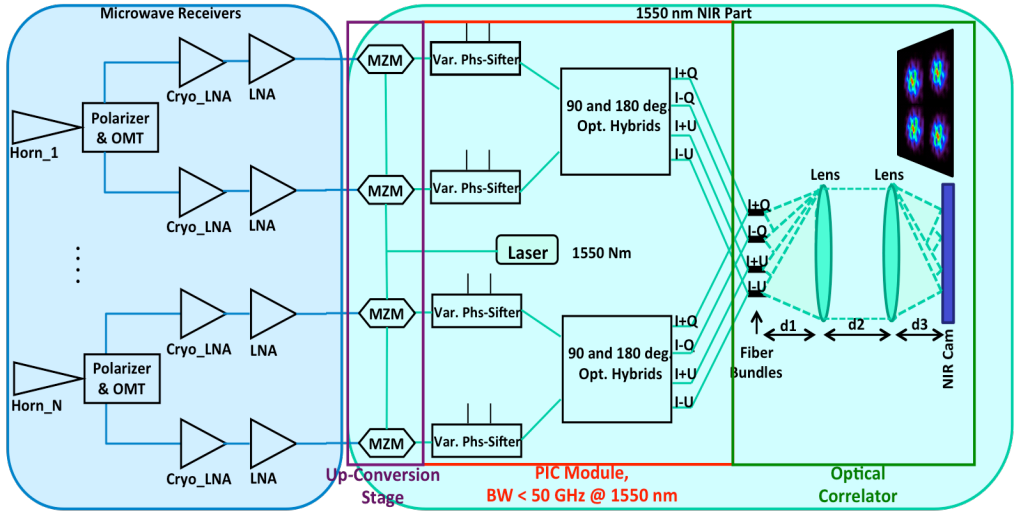
Plans for a Large Format Interferometer with Optical Correlator.

Instituto de Física de Cantabria

DICOM

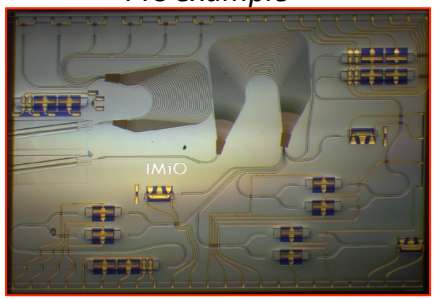
MANCHESTER 1824 The University of Manchester

Optimised Instrument Scheme



- 4f configuration (d_1=d_3=f and d_2=2f) for direct image (NIR detection stage).
- 6f configuration (d_1=f, d_2=3f and d_3=2f) for interferometry (NIR correlator).
- PIC Module can be fabricated in InP technology at HHI Fraunhofer (Berlin, Germany)

PIC example



- **Timescales**:
  +2 years to produce the correlator prototype for 10-20GHz and test the technology in direct image mode at observatory and in interferometry mode at laboratory.
  +2 years to implement a 30 GHz up-conversion stage and couple the optical correlator with the TGI receivers to test the interferometer concept at 30 GHz.
- Planned location: Teide Observatory.

Technological Demonstrator Status

The cryostat is being tested in Roma

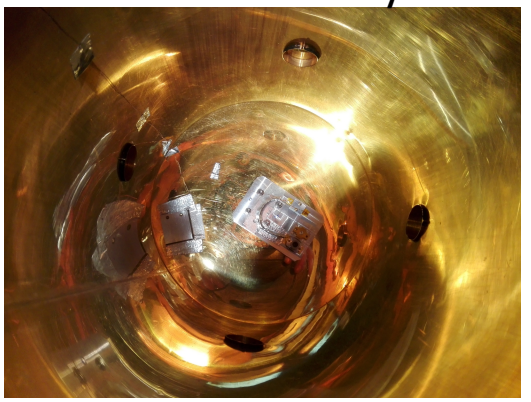
In parallel: testing of the TES arrays in Paris

In the coming months:

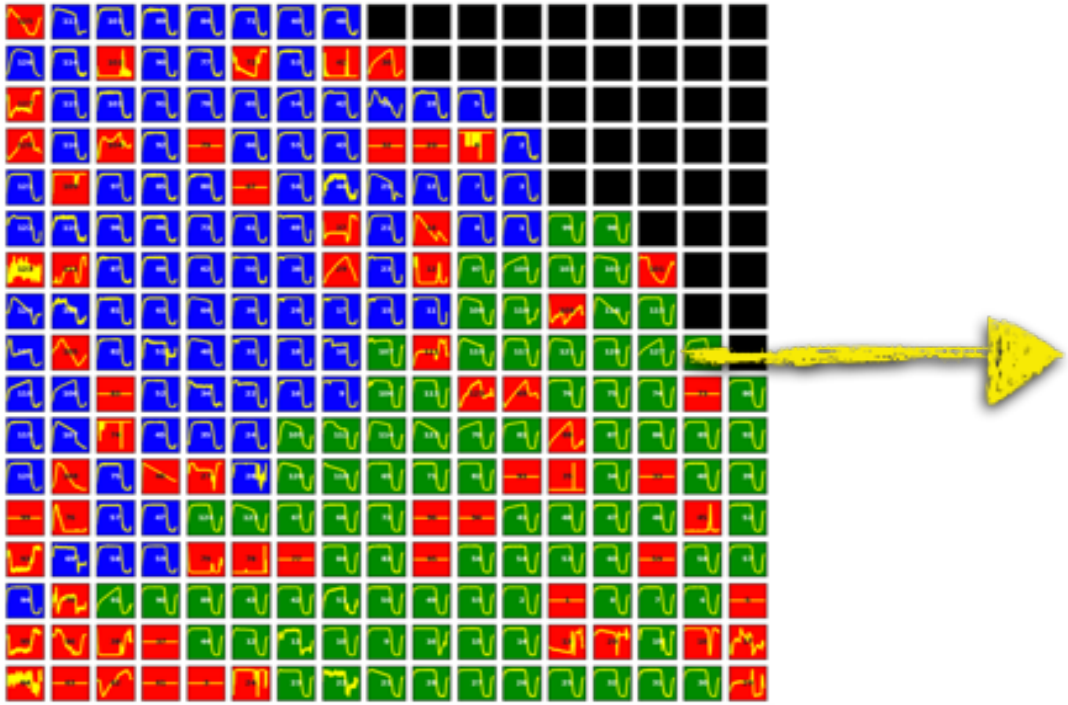
Integration of the Technological Demonstrator

+ extensive integrated in-lab testing

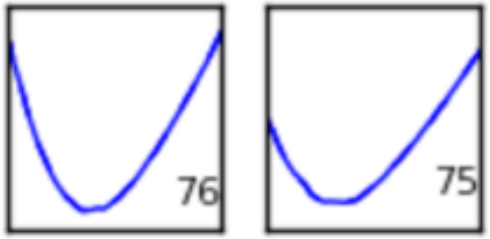
C fiber in a test cryostat



QUBIC TES array: measurement of a heat pulsed signal (C fibers)



zoom for 2 TES



corresponding I(V)

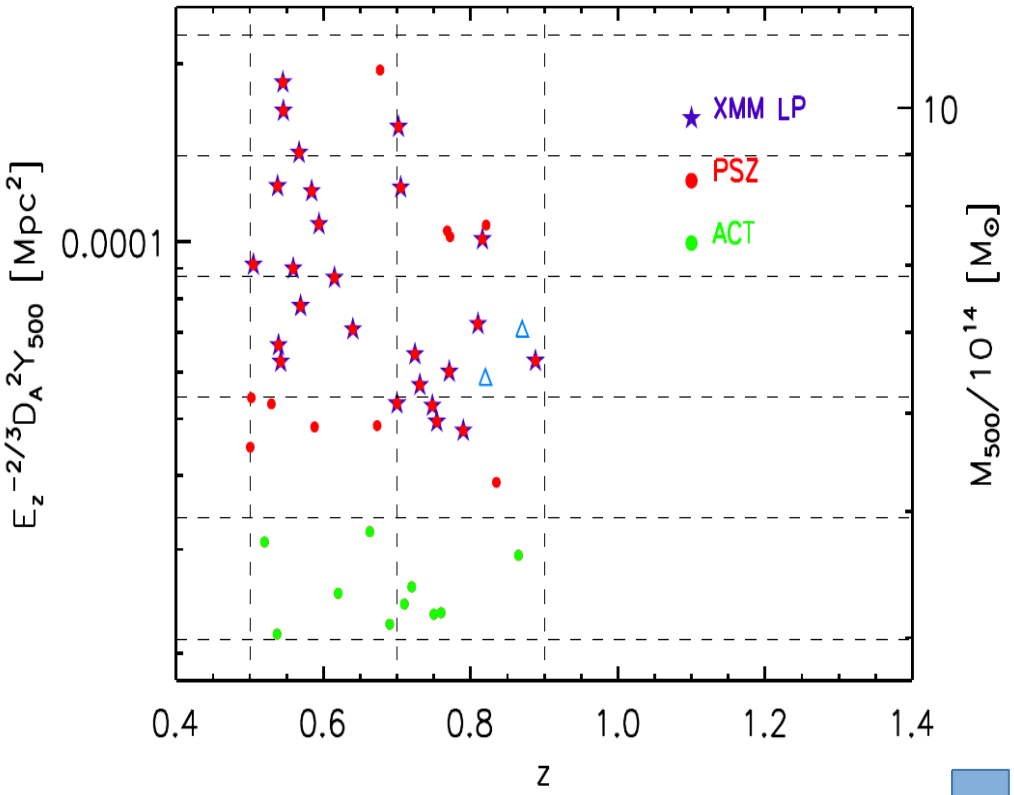
Specifications and observation strategy

Telescope diameter [m]	2.5
Resolution [arcmin]	from 5 to 1.7
FOV [degrees]	1
Number of detectors	600
Frequency range [GHz]	80 - 280
Number of frequency bins	up to 200
Spectral resolution [GHz]	1-10
Modulation [Hz]	1-10
NEP [W /Hz$^{1/2}$] BLIP	4.35 10^{-16}
NEFD [mJy/Hz$^{1/2}$] BLIP	68
NEFD per frequency bin [Jy/Hz$^{1/2}$] BLIP	1.44

- Astrophysical targets :
  - Low redshift clusters from Planck tSZ catalogue
  - Planet and bright radio sources for spectral calibration
- Atmospheric emission correction :
  - 5 interferograms per second to avoid atmospheric variations
  - Hardware instantaneous subtraction of atmospheric background
  - Filter out atmospheric absorption bands

- More work in simulations and data analysis is in progress

NIKA2 SZ Large program



One of the 5 NIKA2 LP (1300h in total)

- **300 hours** of tSZ observation
- **50 high redshift clusters 0.5 < z < 1.0**
- tSZ selected clusters from Planck and ACT catalogues

Ancillary data

- X-ray follow-up with XMM
- Optical data using GranTeCan
- MUSIC hydrodynamic simulations

Main goals

- In-depth study of ICM
- Thermodynamic properties: pressure, density, temperature and entropy profiles
- Mass – tSZ flux relationship

Redshift evolution of:

- Thermodynamic quantities profiles
- Scaling laws and hydrostatic bias

Variation of cluster properties with:

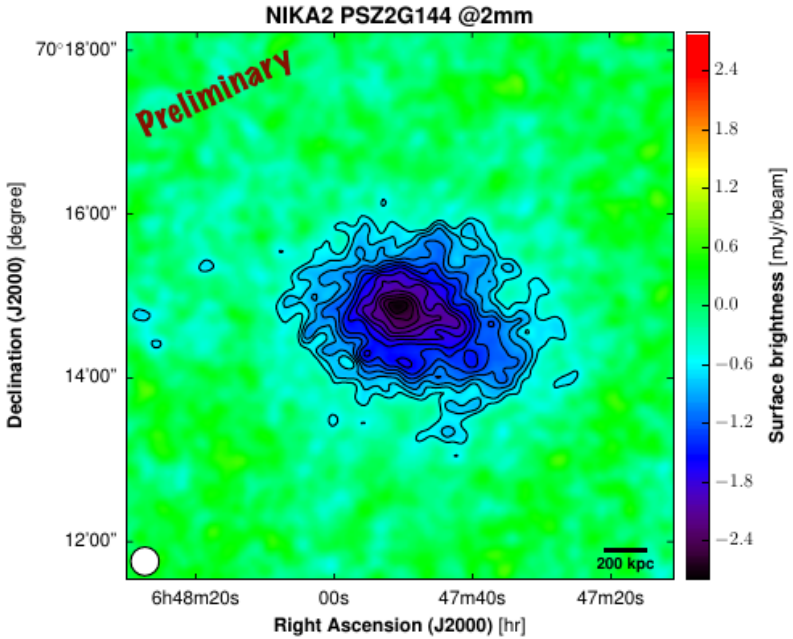
- Dynamical state (mergers)
- Morphology (ellipticity)

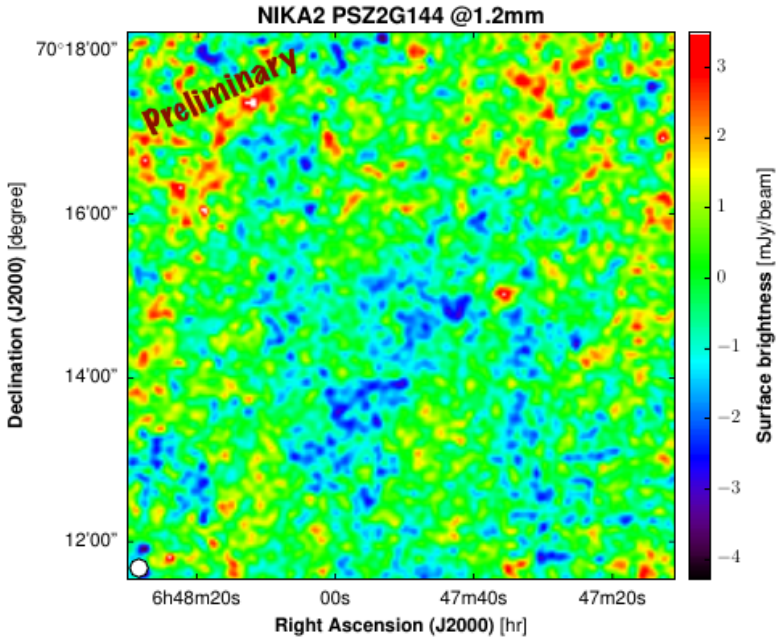
First NIKA2 SZ LP cluster

PSZ2 G144

- Planck tSZ detected cluster at redshift, z = 0.58, high mass M_{500} = 7.8 x 10^{14} $M_{\odot}$
- 11h observations with NIKA1 in poor weather conditions (atmospheric opacity 0.3@225 GHz)
- Already observed: SZ – Mustang & Bolocam, X-rays - XMM

[Ruppin et al, 2018]





Very promising results, detailed analysis on going.